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A Systematic Analysis of Accessibility Education Within Computing Disciplines

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A dissertation submitted in partial fulfillment of the requirements for the degree of
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Abstract

Accessible technologies improve the usability for all users, including 1 billion people in the world who have a disability. Although there is a demand for accessible technologies, there is currently no requirement for universities to integrate this content within the computing curriculum. A systematic comparison of teaching efficacy is important to effectively prepare future computing professionals with the skills to create accessible technologies.

This dissertation contains a mixed-methods cross-sectional and longitudinal analysis of undergraduate Software Engineering and Information Technology students' learning of accessibility. Four teaching conditions were assessed at Rochester Institute of Technology: *content lectures, projects, exposure to stakeholders with a disability, and collaboration with a team member who had a disability.* Evidence of student learning was obtained through questionnaires, project reports, and interview data. Student learning was quantified by a ***knowledge*** of programming techniques, ***awareness*** of accessible technologies, and ***attitudes*** towards individuals with a disability.

The cross-sectional analysis spanned three years (spring 2016-2019), fourteen courses, and seven distinct professors. We found that students in all conditions gained an increased knowledge of implementation methods. Students who were *exposed to a stakeholder with a disability* obtained significantly higher scores in their *prosocial sympathetic attitudes, awareness*

of accessible technologies, and knowledge of programming techniques following the course. Students in the other conditions obtained significant changes in only a subset of these measures.

While students in all conditions obtained significantly higher *knowledge* scores in the short term, only students who had *a project* or a *team member with a disability* sustained significantly higher *knowledge* scores two years after exposure. In interviews, senior-level students revealed that there were multiple factors outside the classroom that dissuaded them from furthering their learning of accessibility. Students mentioned a lack of person-centered topics in major software development processes (e.g., agile, waterfall) and workplace tasks. Without direct reinforcement, students focused on functional software requirements and expressed that accessibility would only be necessary in select front-end development career paths or domains.

While current work in computer accessibility education evaluates learning during, or immediately following, one course, this dissertation provides a systematic comparison of student learning throughout multiple courses and instructors. The findings within this dissertation may be used to inform future curriculum plans and educational initiatives.

Acknowledgments

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Preface

The purpose of this dissertation is to advance the training in accessibility of computing students by evaluating the efficacy of varying teaching methods. It is understood that the terms used in this dissertation may vary in the future. As Stiker [1999] explains,

> *"There is no disability, no disabled, outside precise social and cultural constructions; there is no attitude toward disability outside a series of societal references and constructs. Disability has not always been seen in the same way." [123]*

In this dissertation, we adopt the meaning of disability as defined by the International Classification of Functioning, Disability, and Health (ICF) because it is the current scientific standard in the 191 member states of the World Health Organization [148]. The ICF model defines disability as a dynamic interaction between an individuals' body functions and their participation in all areas of life [147, 148]. In addition, the ICF model highlights the role of environmental factors, such as assistive technologies, in determining ones' level of participation in society. Inaccessible technologies can therefore, increase the severity of ones' disability. In the United States, the ICF model is consistent with nondiscrimination laws, such as the Americans with Disabilities Act, where disability is defined as an *"impairment that substantially limits one or more major life activities"* [136].

In this work, we also use person-first language (e.g., "an individual with a disability"). The term deaf, rather than Deaf, is more commonly used in this dissertation to refer to hearing loss. However, Deaf is also used to highlight instances when students discuss Deaf culture. While the terms in this dissertation may differ in the future, we hope that these findings will contribute to the development of more accessible technologies.

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Chapter 1

Introduction & Motivation

Although there is an ethical, regulatory, and market need for accessible technologies, there is a gap in the current preparation of future computing professionals – **curriculum standards do not require instruction on accessibility and there exists no systematic analysis of teaching efficacy** [2, 72, 100]. Some instructors have acknowledged the need for accessibility education and have voluntarily incorporated content within computing courses [100, 119]. These instructors have reported anecdotal evidence on the efficacy of various teaching methods. As Lewthwaite et al., explain,

> *'... the majority of pedagogic research papers comprise of teacher's reflections on their own practice and course design... However,*

> *there is a need for the field to move beyond accounts of specific modules and teaching teams so educators can call upon a substantive body of literature characterized by systematic debate, cross-case investigation, and evaluation of teaching and learning to inform their practice.' [72]*

To the best of our knowledge, this dissertation contains the first systematic evaluation of accessibility teaching methods. The overarching research question for this work was:

How effective are accessibility educational methods in increasing computing students' learning?

Four teaching ***conditions*** were systematically assessed based on related work: *content lectures* [43, 49, 83], *projects* [49, 58, 83], *interactions with end users* [9, 16, 61, 77], and *collaborations with team members with a disability.* These teaching ***conditions*** were reviewed across seven semesters, 14 courses, and seven professors, thereby increasing the validity of the results.

The findings contained in this dissertation not only outline which teaching methods are most effective, but also indicate which factors outside the classroom influence students' learning. In a longitudinal study, multiple external motivators and workplace experiences were identified as impacting students' willingness to maintain their skills in accessibility. Chapters 9 and 10 outline the different external factors that influenced students' outlook of accessibility. Chapter 2 of this dissertation details the market benefits, ethical motivations, and government laws that contribute to the demand for accessibility-aware computing professionals.

1.1 Overview and Organization

While later chapters of this dissertation will describe the methodologies used, this section provides a brief overview of key details so that the specific research questions may be presented to the reader in this introductory chapter.

To examine the overarching research question presented above, student learning was measured through ***knowledge*** of implementation techniques, ***awareness*** of accessible technologies, and ***attitudes*** towards individuals with a disability. Accessibility ***knowledge*** and ***awareness*** was calculated through a questionnaire designed by Huenerfauth et al. [54] and ***attitudes*** were quantified through the Interactions with Disabled Persons Scale [45]. The questionnaire was collected at three moments in time to assess students' short and long-term learning (refer to Chapters 4 and 5):

a. "pre" - Students completed the survey before the accessibility modules.

b. "post" - Students completed the survey at the end of the semester.

c. "senior" - Students completed the survey 12-18 months after the course concluded, e.g. typically during the "senior" year of their degree.

Qualitative data (project reports and interviews) was also collected to identify instances when students applied their knowledge of accessibility. Project reports were collected during the course (Chapter 8) and interviews were conducted 12-18 months after the course (Chapter 9).

Data was gathered from students in each ***condition*** (*content lectures, projects, end users with a disability, and team members with a disability*). As outlined in Table 1.1, the ***conditions*** were nested so that a student who collaborated with a team member with a disability also gained the other teaching ***conditions*** of *content lectures and projects.* The teaching ***conditions*** were embedded into two computing degree programs (Software Engineering and Information Technology) at Rochester Institute of Technology, where they were the only required formal instruction on accessibility [107]. The manner in which this content was embedded into the curriculum was accordant with international curriculum guidelines [2, 56] (refer to Chapter 3).

Table 1.1: Teaching Intervention Conditions

	Lectures	Project	End user	Team member
Lectures	Yes			
Project	Yes	Yes		
End user	Yes	Yes	Yes	
Team member	Yes	Yes	Yes	Yes

1.1.1 Research Questions

To evaluate the overarching question of students learning, we developed six specific research questions. Research questions 1 and 2 focused on identifying the teaching ***conditions*** that contributed to statistically significant changes in student learning. To compare the influence of the four ***conditions*** in **RQ1**, students' accessibility ***knowledge***, ***awareness***, and ***attitudes*** were assessed before and after intervention. **RQ2** included a longitudinal comparison 12-18 months after intervention.

RQ 1. Do the four teaching conditions (*lectures, team projects, stakeholders/end users, and team members*) contribute to statistically significant changes in students' **short term** learning? (Chapter 6)

- **RQ 1.1.** Do students in the four teaching conditions report significantly different **knowledge of accessibility implementation methods**?

- **RQ 1.2.** Do students in the four teaching conditions report significantly different **awareness of accessible technologies**?

- **RQ 1.3.** Do students in the four teaching conditions report significantly different **attitudes towards individuals with a disability**?

Hypothesis: Based on related work that identified the benefits of interacting with an individual with a disability [14, 16, 77, 117], it was hypothesized that students who gained exposure to a *stakeholder or end user with a disability* would gain significantly higher accessibility ***knowledge***, ***awareness***, and ***attitudes*** in the short-term. Although studies did not include significance testing [14, 16, 77, 117], the findings suggested that these experiences led to increased empathy [14] and awareness of diversity [16] among students.

RQ 2. Does the Human-Computer Interaction (HCI) course contribute to statistically significant changes in students' **long term** learning? (Chapter 7)

Hypothesis: Students' pre questionnaire scores were used as a baseline measure to assess long-term learning. It was hypothesized that the measures that yielded significant results in the short-term (RQ1) would continue to do so in the 12-18 month interval. That is, students would retain the lessons from the course as they would have future opportunities to reapply these insights in consequent course projects.

The next three research questions focused on students' project choices and the outside-of-the-classroom experiences that may have shaped their education in regard to accessibility:

RQ 3. Do teams consider the needs of individuals with a disability at the onset of a project? (Chapter 8)

- **RQ 3.1.** Do the four teaching conditions report significantly different tendencies in the consideration of individuals with a disability?

Hypothesis: It was hypothesized that the majority of students would not consider the needs of individuals with disabilities. Related work suggested that students could be reluctant to seek requirements from individuals with a disability [16, 77]. In Software Engineering, students had also been found to use accessibility testing less often, when compared to other software testing methods [62]. Furthermore, related work suggested that if users with a disability were considered, they would primarily be individuals who had visual or motor impairments [101].

RQ 4. What sources of information do student teams use to justify their decisions related to accessibility? (Chapter 8)

Hypothesis: It was hypothesized that students would primarily seek insights from individuals outside the team. Related work suggested that automated accessibility evaluations, conference proceedings, and guidelines, could be time-consuming to interpret and navigate [60, 66, 144]. Furthermore, accessibility guidelines and evaluations had been found to provide students limited insights on how to apply accessibility effectively [57, 126, 152]. For example, students could create navigation that conformed with established guidelines, only to learn that screen readers mispronounced content, rendering it incomprehensible [126]. Automated evaluation tools had also been found to report false positives [130, 152].

RQ 5. In interviews about their educational experience during their university career, what factors do students believe have influenced their accessibility knowledge? (Chapter 9)

Hypothesis: It was hypothesized that students would identify challenging factors that limited their learning of accessibility, such as those found in academic and industry settings: challenges with accessibility testing [62], requirements elicitation [77, 117], time restrictions [130], budget [130], and conflicting project requirements [130]. Researchers have also indicated the influence of external factors on students' motivations to learn new topics [55, 86]. External factors, such as a supportive top-level management have also been cited to influence computing professionals' commitment to accessibility [13]. It is possible that different challenges and motivating factors influenced students' knowledge of accessibility.

RQ 6. What educational resources or instructional methods do students wish they would have had, to better prepare them to create accessible technologies? (Chapter 10)

Hypothesis: Related work suggested that computing degree programs tended towards introverted learning behaviors [22], whereby information was primarily gained through online resources and factual information rather than other people [18]. Furthermore, prior studies highlighted how computing students regularly acquired knowledge through self-directed learning [86] and the Internet [37]. As such, it was hypothesized that students would primarily request resources that could support them in this style of learning, such as through automated evaluation tools and programming libraries.

1.2 Contributions to Knowledge

A systematic comparison of teaching activities is important in informing the training of future computing professionals. Consistent with the findings of Putnam et al. [100], and to the best of our knowledge, this is the first systematic study of accessibility instruction methods within computing disciplines. Liffick for instance, developed an NSF-funded course on assistive technology design [73], but did not assess the efficacy of the teaching methods [74]. Similarly, Waller et al. presented the integration of accessibility education throughout a four year curriculum, but did not include an evaluation of teaching efficacy [140]. Additional prior work will be discussed in Chapter 2. The main contributions of this dissertation are itemized below:

- We systematically examined the efficacy of four teaching conditions, recommended in related work, among Software Engineering and Information Technology students. The teaching conditions were examined throughout seven semesters from spring 2016 to 2019.

- We evaluated the longer term effects of the accessibility modules through questionnaires and interviews. During interviews, students provided multiple recommendations and listed factors outside the classroom that contributed to their perceptions of accessibility.

- We described all data collection and analysis methods within this dissertation to enable study replication.

These contributions to knowledge are meaningful for the continued development of computing curricula and for the budgetary justification of instructional plans. By providing a systematic analysis of common teaching ***conditions***, we also cultivate new discussions on teaching methods. This work may contribute to future study replication and the eventual expansion of the field into learning analytics. In a 2019 study for instance, the replication rate for general computing education research was found to be similar to psychology, business, and biology disciplines [48]. However, none of the identified replication studies from 2009 to 2018 investigated accessibility instruction within computing disciplines [48].

1.3 Publications & Personal Contributions

All prior reporting was conducted with up to three semesters of data and without a differentiation of each ***condition***. Below are the publications related to this research project. Each item contains a list of my personal contributions:

- Matt Huenerfauth, Stephanie Ludi, and Vicki Hanson. 2015. CCE STEM: Ethical Inclusion of People with Disabilities through Undergraduate Computing Education. (2015)

  - This successfully funded National Science Foundation (NSF) proposal (award 1540396) included the questionnaire and teaching ***condition*** artifacts designed by Huenerfauth et al. Data collection for the project began spring 2016, and I joined as the PhD student on this grant in summer 2017. There are five teaching ***conditions*** discussed in this NSF proposal. The original fifth teaching ***condition***, *homework assignment on accessibility*, was removed from the final implementation plan as funding was provided for four years rather than five years.

- Ashley Miller. 2016. Development of a Statistical Toolkit for the Ethical Inclusion of People with Disabilities through Undergraduate Computing Education Research. Masters Thesis. Rochester Institute of Technology.

  - This masters thesis compared one semester of *pre* questionnaire responses (spring 2016) collected from Computer Science, Information Technology (IT), and Software Engineering students. Comparisons for the pre questionnaires were made by students' major rather than by teaching condition. Although I did not contribute to this work, the nodes proposed by Miller [90] informed the final qualitative nodes used in this dissertation.

- Nidhi Palan, Vicki Hanson, Matt Huenerfauth, and Stephanie Ludi. 2017. Teaching Inclusive Thinking in Undergraduate Computing. In *Proceedings of the 19th International ACM SIGACCESS Conference on Computers and Accessibility (ASSETS'17).* ACM, New York, NY, USA. 399-400
  - This publication presented the questionnaire by Huenerfauth et al. [54] and provided preliminary results from two semesters (spring 2016-fall 2016). The only teaching ***condition*** considered in this work was *lectures*. At the end of the semester, students more frequently considered individuals with disabilities during requirements gathering and they exhibited greater ***knowledge*** of accessibility implementation techniques. This work began before I joined the team in summer 2017, but it has helped inform the hypotheses to research questions 1 and 2.
- Stephanie Ludi, Matt Huenerfauth, Vicki Hanson, Nidhi Rajendra Palan, and Paula Garcia. 2018. Teaching Inclusive Thinking to

Undergraduate Students in Computing Programs. In *Proceedings of the 49th ACM Technical Symposium on Computer Science Education (SIGCSE'18)*. ACM, New York, NY, USA. 717-722

- This publication reported on three semesters of data (spring 2016-2017) to begin measuring the differences in the teaching conditions. To provide preliminary analysis, the four conditions were categorized into two conditions: *exposure* and *no exposure* to an individual with a disability. For this work, I developed a thematic coding procedure for the creation of a qualitative dataset of students' projects (Chapter 8). The nodes created for this procedure were made in collaboration with one research assistant and reviewed by three additional researchers to ensure clarity. Using these nodes, I qualitatively coded 236 project submissions [78]. Through an evaluation of both the qualitative and quantitative data, our team found that ***knowledge*** may not be enough to motivate students to create accessible technologies.

The research questions for this dissertation build on prior and related work by examining each of the four teaching ***conditions***. Reseach questions

1 and 2 were consistent with the NSF proposal [54] and were the basis for this dissertation. Neither research question 1 nor 2, however, have been previously examined. Although research questions 3, 4, and 5 were not part of the NSF proposal [54], they supported the initial intent of understanding student learning in the short and long-term. This multi-year, systematic, research may contribute to the development of a computing curriculum that considers accessibility.

Chapter 2

Related Work

There is a need for additional computing professionals who have the skills and inclination to develop accessible technologies [42, 70]. Such computing professionals possess the knowledge to create multi-modal information systems that increase the overall usability of a technology [70]. A lack of experienced professionals has been cited as a major contributor to the declining accessibility of existing systems [71, 76, 143]. In a review of 50 websites for example, the overall accessibility was found to decrease over a one year period [71]. In addition, in a survey of 148 companies worldwide found that the greatest barrier to creating accessible products was a lack of awareness in inclusive design [35].

In this chapter, we discuss the factors that contribute to the demand for computing professionals that are experienced in accessibility topics. We continue this discussion with an overview of current training efforts and the measures that have been used to assess teaching efficacy.

2.1 Motivations for Teaching Accessibility in Computing

This section discusses three drivers for accessibility-aware computing professionals: *ethical motivations, market need, and government regulations.*

2.1.1 Ethical and Moral Reasoning

One driver for accessibility is the ethical desire to allow basic human rights to all individuals. Currently, there are one billion people worldwide who have a disability [149] and this number is expected to rise throughout the years 2000 to 2030, when the population 65 years and older will increase [134,149]. Accessible technologies also support individuals with work or sport-related injuries. From 2011 to 2014, there were 8.6 million sports-related injuries among individuals in the United States [115]. Therefore, the creation of accessible technologies is not only essential to support current populations, but also essential for sustaining future users of technology.

The creation of accessible technologies involves social participation in health services, political involvement, economic opportunities, and personal security [34, 149]. This moral motivation echoes the Association for Computing Machinery Code of Ethics:

> *"An essential aim of computing professionals is to minimize negative consequences of computing, including threats to health, safety, personal security, and privacy. When the interests of multiple groups conflict, the needs of those less advantaged should be given increased attention and priority.*
>
> *Computing professionals should consider whether the results of their efforts will respect diversity, will be used in socially responsible ways, will meet social needs, and will be broadly accessible." [4]*

Importance of Creating Accessible Technologies

Popular technologies such as personal computers [34,59,124] and mobile devices [38] can be inaccessible to individuals with a disability. In a 2010 survey of adults in the United States, only 54% *with* a disability were found to use a computer or other electronic device to access the Internet [124]. Studies have also reported the features that contribute to inaccessible websites [71, 143], such as image-based text [126], CAPTCHA [79], flashing animations [153], and high bandwidth content [34]. International accessibility guidelines, such as the Web Content Accessibility Guidelines [150] and Accessible Rich Internet Applications (WAI-ARIA) [151], provide guidance for website developers on best implementation practices. Accessible websites are especially important in health and government domains, where individuals with disabilities have been found to more frequently access information online than individuals without disabilities [34].

In addition to health and social participation, computing professionals have an opportunity to impact the economic security of individuals with a disability. In 2010, only 21% of individuals with a disability in the United States reported being employed part or full time [124]. This is in contrast to 59% of individuals *without* a disability who reported being employed [124]. Workplace accommodations, such as closed-circuit televisions, screen magnification software, and text to speech programs, have been found to impact an individuals with disabilities' job retention [27, 28]. These assistive technologies can be incompatible with an employer's system updates, creating obstacles for individuals with disabilities [27, 28, 79]. In a report of workplace environment, Makkawy identified this as a central issue expressed by participants [79]. One participant explained:

> *"When the IT department heard that someone had vision issues, they automatically assumed the magnifier was the solution, and it wasn't. My workplace uses a [C]itrix environment, which is not compatible with some screen readers, such as Zoom Text... My IT department has significant lag time in making accessible features available to me as they determine whether it is compatible with our work environment or will destabilize it." [79]*

As outlined in the ACM Code of Ethics, the aim of the computing profession is to minimize the negative consequences of technology towards health, safety, security, and privacy. By creating accessible technologies, computing professionals can advance the availability of technology among individuals with a disability. These technologies have the opportunity to improve the health, social participation, and the economic opportunities of individuals with a disability.

2.1.2 Market Need

Financial incentives are the second major driver for accessibility-aware computing professionals. As mentioned in Section 2.1.1, there are 1 billion people in the world who have a disability and this number is expected to rise as the population ages 65 and above increases [134, 149]. Family members of individuals with disabilities are also direct consumers of accessible technologies [134]. In a 2018 study, a record 64 million individuals lived in multigenerational homes in the United States [25], impacting potential purchase decisions for home automation and security systems, among others. More importantly however, accessibility has been found to lead to technology innovations, as will be discussed in the next subsection.

All Users Benefit from Accessibility

The flexible input and output modalities of accessible technologies accommodate a larger number of participants with situational, temporary, or permanent impairments. Audiobooks for instance, were first published to benefit individuals who had blindness or low vision [3], but are now widely used for entertainment and education purposes. Other accessibility features, such as autocomplete, voice-enabled devices, and keyboard shortcuts (e.g., Ctrl + C to copy), were initially designed for the individuals with disabilities, but are now broadly used to increase productivity [15, 114].

Aside from improving the general usability, accessible technologies have uncovered *new* benefits for individuals *without* a disability. Video captioning for instance, was initially designed to annotate sound and dialog for individuals who were deaf or hard of hearing [93]. Video captions have also been found to increase literacy among children, listening comprehension among second-language learners, and short-term memory of adults [44].

Industry Demand

Companies with demand for accessibility-aware computing professionals include Google, Facebook, Twitter, Microsoft, PayPal, and Wordpress, where dedicated accessibility teams focus on the development of innovative technologies [12]. Accessibility is also important to companies such as Intuit, AT&T, and Adobe, who are founding members of the organization Teach Access [125]. Teach Access works to bolster accessibility efforts in industry and academia [67, 125]. As highlighted by Teach Access, multiple companies now recruit computing professionals with accessibility knowledge, including

Capital One, Dropbox, and Oath [125]. Dropbox's Software Engineering positions highlight the need for accessibility knowledge:

> *"As a UI Engineer/Accessibility you will work principally on delivering and improving the user experience and interface of our products and component libraries, with a focus on improving and addressing accessibility concerns. You will partner with other engineers, managers, product owners to make sure all our shared components and end-user experiences meet the accessibility needs for our web products, and you will ensure our core components remain accessible by delivering the scalable and repeatable tooling that makes this possible." [125]*

In summary, the market need for accessible technologies is informed by user demand and companies' desire to deliver innovative solutions. The development of accessible technologies supports the widespread use of technology.

2.1.3 Government Guidelines

Government guidelines are the third major driver for accessibility-aware computing professionals. As discussed in Section 2.1.1, accessible technologies play an important role in individuals' opportunities to participate in society. In the United States, accessible technologies are regulated through the Americans with Disabilities Act [136], the Air Carrier Access Act [132], the 21st Century Communications and Video Accessibility Act [39], and the Hearing Aid Compatibility Act [133]. In 2015, more than 240 businesses were sued in federal court due to inaccessible websites [103]. This figure surged in 2018, when website-access lawsuits more than doubled (2,250) in comparison to 2017 (814) [104]. The demand for accessibility-aware computing professionals will continue to increase as compliance requirements commence for new provisions:

- **August 2003:** The Federal Communications Commission updated the Hearing Aid Compatibility Act, requiring all mobile devices to be compatible with hearing aids [133].
- **October 2011:** The United States District Court of Massachusetts identified websites as a place of public accommodation, based on the definitions in the Americans with Disabilities Act [138].

- **November 2013:** The Air Carrier Access Act update required that all U.S. and foreign air carriers provide fully accessible websites by the year 2016 and accessible kiosks by 2023 [137].
- **January 2017:** The Rehabilitation Act update ensured that all government information technology tools were usable by individuals with disabilities [131]. Compliance was required by the year 2018.

As compliance requirements to these regulations commence, there is an increased need for companies to ensure their employees are knowledgeable about accessibility.

2.2 Rising Efforts in Educating Computing Students about Accessibility

While prior sections of this chapter call attention to the ethical, market, and regulatory needs for accessible technologies, current computing curricula do not require education on these topics. In this section, we discuss curriculum guidelines in detail. We also compare the teaching approaches instructors have voluntarily used to prepare undergraduate computing students in accessibility.

2.2.1 Curriculum Guidelines

There are two major international curriculum guidelines for computing education: the ACM Joint Task Force Computing Curricula (ACC) and the Software Engineering Accreditation Board for Engineering and Technology (ABET). Accessibility was first mentioned in a 2008 ACC interim report [21, 98] and then formally added to the 2013 ACC curriculum guideline [56]. On the other hand, the first mention of accessibility within the ABET criteria was in 2017 [2]. Although both the ACC and ABET now mention accessibility, there is *no requirement* for universities to add this content within their curricula, as will be discussed in the subsequent sections.

ACM Joint Task Force Computing Curricula

The ACC was first published in 1968, and has been consecutively published approximately every decade. In 2013, the ACC introduced a Human-Computer Interaction (HCI) core intended to expose all students to the diverse needs of end users [56]. The HCI core recommended the instruction of color perception, ergonomics, cognition, user-centered development, and system testing [56]. Aside from the HCI core, the ACC also outlined accessibility education within computing ethics and object oriented programming courses [56]. Researchers have reported that current computing ethics courses, however, do not focus on accessibility, but rather on privacy, security, and business practices [82, 84]. Countries around the world, such as the United States, United Kingdom (United Kingdom Quality Assurance Agency), and China (China Computer Federation), have been found to refer to the recommendations in the ACC [91]. It is possible that accessibility will begin to be integrated in curricula once universities begin referring to the 2013 ACC update.

Accreditation Board for Engineering

Unlike the ACC guidelines, the ABET criteria *is required* for Software Engineering (SE) programs that seek accreditation [1]. In 2017, a section was added for *Engineering Design* to expose students to accessibility, ergonomics, maintainability, usability, and other design constraints [65]. While accessibility education is *not required* for ABET accreditation, the addition of this term brings attention to its need in engineering design. Universities may choose any constraint for engineering design, accessibility being one option [65]. In 2018, there were a total of 793 ABET-accredited universities including Rochester Institute of Technology (RIT), Harvard University, and Massachusetts Institute of Technology [1].

In summary, although there is rising awareness of the benefits of accessibility, there is no current requirement for universities to implement this content. In a 2018 survey of 1,857 computing instructors, the greatest barrier to teaching accessibility was that it was *'not a core part of the curriculum'* [119]. Similar observations were found by Teach Access [125] and the State of Maryland (USA) [33]. In 2014, the state of Maryland (USA) passed *House Bill 396* to evaluate accessibility education in computing disciplines during the years 2014-2017 and to generate a budgetary plan for improving it [33].

2.2.2 Current Undergraduate Computing Curricula

Although accessibility is not required in computing curricula, computing instructors have voluntarily incorporated this content within Human-Computer Interaction (HCI) [61, 69], web development [7, 49, 58], and service design [9, 16, 83] courses. This section discusses course activities and lecture material that have been proposed by prior researchers.

Human-Computer Interaction Courses

Traditionally, HCI courses have employed a user-centered approach to understanding technology in the context of a users' environment and tasks [61]. The focus of HCI courses however, has not been on the creation of accessible technologies, which has led to reports of students deprioritizing accessibility and considering it as an afterthought [96, 117]. To further motivate students to consider accessibility, HCI instructors have coordinated student interactions with individuals with a disability. Through these interactions, students have been found to gain an increased awareness of accessibility [61, 117].

Website Development Courses

Web development courses have been reported to include lectures on accessibility guidelines [58], where traditionally there has not been a focus on accessibility programming methods [49, 58, 108, 141]. Numerous lectures and projects have been proposed by instructors in order to expose students to accessible website development [96, 108, 141, 153]. For instance, Youngblood suggested the addition of accessibility evaluation tools (e.g., WAVE) to accompany accessibility guidelines [153], and additional instructors have created custom simulators to accompany accessibility guidelines [7, 36, 43].

The efficacy of these methods has been anecdotally reported: Harrison found that when students were asked to apply web accessibility methods and evaluate their work, they were able to experience the limitations of automated evaluation tools [49]. Bobby, the accessibility evaluation software by Watchfire, was found to present errors even when students corrected them [49]. The presence of false positives in accessibility evaluation tools was also observed by Trewin et al. [130].

Service-Based Courses

Service-based courses have also been used as an opportunity to integrate accessibility education within computing disciplines. These courses integrate stakeholders with a disability within team projects to further students' skills in project management and effective customer interaction [9, 16]. Service-based courses have also been reported to develop students' advocacy for the end user [16]. To provide more consistent results in service-based courses, instructors have proposed establishing student expectations early in the course [16], structuring projects to reduce stakeholders' workload [80], and communicating the scope of the project to stakeholders [63].

Specialized Courses

Specialized electives or degrees specifically focused on accessible technologies have had less traction in the United States, as students were less likely to enroll without an awareness of their widespread benefits [10, 99]. Researchers have also warned that creating specialized courses on accessibility can result in the creation of assistive technologies rather than mainstream technologies. As Bigelow describes [8],

> *"Though the recognition of accessibility is clearly important, it may hinder students from looking at the broader scope of the importance of designing for all" [8]*

In addition to HCI, web development, and service-based courses, a limited number of researchers have proposed the addition of accessibility content within software development [74], system design [68], and data structure courses [140]. In data structure and algorithm courses, Waller et al. suggested that student projects require considerations for diverse users [140]. For instance, students could develop an algorithm that considered erroneous text inputs by individuals with motor impairments [140]. To highlight the benefit of accessibility for all users, we incorporated accessibility modules within established HCI courses at Rochester Institute of Technology.

2.3 Efficacy of Teaching Methods

In this section, we discuss how instructors have begun to assess the efficacy of accessibility education through questionnaires and student deliverables. Section 2.4 expands the related work to disciplines outside computing.

2.3.1 Lectures

Instructors have used lectures to impart technical and ethical knowledge among students [94, 141]. In a 2017 study of 49 SE and IT students, Palan et al, found that students exhibited greater awareness of accessible technologies and knowledge of implementation techniques following lectures [94][1]. Following content lectures, Palan et al. also found that students more frequently considered individuals with a disability in requirements gathering [94]. The frequency of considering individuals with a disability during requirements gathering was assessed through a revised version of

[1]This study was conducted by researchers associated with the NSF grant referenced in this dissertation.

Ludi's [77] voting scenario question. Palan et al.'s study provided new measures for quantifying accessibility awareness and knowledge among IT and SE students [94]. However, it remained unclear whether lectures could be effective in changing students' attitudes towards accessibility.

Instructors have anecdotally reported that the reliance on accessibility lectures led to no changes in students' attitudes towards accessibility [99, 100, 108, 109]. In an interview of 18 computing faculty in the United States, Putnam et al. gathered that the reliance on lectures for accessibility education could lead to misinterpretations of a disability:

> *"I think [accessibility] is a subject that is difficult to appreciate from a sort of book-learning point of view. And.. it can be hard to understand, it's easy to misunderstand" [99].*

Similarly, Traynor reported students expressing the benefits of experiential learning as opposed to lecture materials. In the course, students worked with end users who had a disability [129]:

> *"The idea of Human Computer Interaction is quite abstract in class, but being able to observe [it] in real life makes it a lot easier to understand" [129].*

Instructors have suggested demonstrations of accessible technologies to enhance students' learning [41, 74]. Harrison found screen readers to be effective in reinforcing accessibility concepts among students, but no analysis was made in regards to its' efficacy [49]. To date, limited analysis is available on the holistic benefits of accessibility lectures.

2.3.2 Stakeholders with a Disability

Prior research has reported students gaining an appreciation for accessibility after working with stakeholders with a disability. For instance, Ludi measured students' interest in recruiting stakeholders with a disability using a voting scenario questionnaire [77]. During the course, a subset of students completed team projects with a stakeholder with a disability, while the remaining students had a stakeholder who did not identify as having a disability. Students with exposure to a stakeholder with a disability, more frequently mentioned the need to gather accessibility-related project requirements when completing the questionnaire at the conclusion of the course [77].

Kurniawan et al. measured students' interests in accessibility following interactions with individuals with a disability [64]. In a questionnaire, students reported gaining an increase in awareness of accessible technology but they did not feel fully equipped to interact with *all* individuals with a disability [64].

Shinohara et al. assessed 42 Informatics students' accessibility knowledge through thematic coding of student journals, project deliverables, and observations [117, 118]. Students reported benefiting from exposure to individuals with a disability, content lectures, and a guest speaker with a disability, when applying accessibility concepts to their projects. Some students also reported feeling less overwhelmed about accessibility requirements, possibly reflecting a change in attitudes towards accessibility [117, 118]. Students mentioned a high motivation to apply the insights they gained from stakeholders:

> *"Working with a person with a disability will affect the considerations I put into the project. If I were making a device for someone without disabilities, I sadly would not have considered factoring in people with disabilities." [117].*

Both Ludi's and Shinohara et al.'s work suggested that student interactions with a stakeholder with a disability resulted in an appreciation for accessible technologies [77, 117, 118]. Additional anecdotal reports supported these findings: Buckley et al. observed students advocating for the end user [16], and Brooks observed students becoming passionate about the transformative power of technology [14]. On the other hand, Kurniawan et al.'s study provided mixed evidence for students' comfort in incorporating accessibility in future work [64].

Additional analysis is needed to determine the short and long-term benefits of incorporating stakeholders with a disability. In contrast to content lectures, the addition of stakeholders with a disability requires more time and monetary resources from instructors [80].

2.3.3 Projects on Accessibility

The majority of studies on accessibility-related team projects incorporate end users or stakeholders with a disability [9, 14, 16, 69, 95, 109]. However, when instructors have not been able to directly integrate end users, they relied on secondary information sources. Carter and Fourney reviewed Computer Science (CS) students' awareness of accessible technology through written submissions [20]. Following accessibility readings, lectures, and projects, students submitted five-item written critiques that detailed challenges and opportunities in the field [20]. As students progressed in the course, their overall average score increased, suggesting that students were engaged in the information and gaining more awareness of accessible technologies [20].

Poor et al. measured CS students' attitudes towards accessibility through a questionnaire, finding that students rated HCI tasks similarly to traditional CS tasks [98]. Although Poor et al. were interested in seeing the effect of accessibility projects, the survey questionnaire did not measure accessibility attitudes directly [98]. The only accessibility related questionnaire item was, *'Implementing policies regarding accessibility'* [98].

Mixed findings have been reported for the inclusion of proxy users (e.g., educational specialists, occupational therapists, psychiatrists, etc.). Anecdotal reports by Kuber suggest that students remained engaged in projects related to accessibility when interacting with proxy users [63]. Some researchers however, have warned that proxy users could lead to misinterpretations of disability [113, 120].

Overall, accessibility projects appeared to be a promising method for engaging students in accessibility content. Additional analysis is necessary to understand the quality of knowledge that students gain when completing projects related to accessibility.

2.3.4 Gap in Knowledge

Related work has provided a preview of possible learning outcomes, but they are limited by scope and methodology. **Existing studies evaluate accessibility education in one or two course section(s), often taught by the authors themselves.** The assessment of efficacy is also limited by one or two dimension(s) of accessibility, such as, ***knowledge, awareness,*** or ***attitudes***. A meta-analysis cannot be conducted to assess all dimensions of accessibility education, as existing studies differ in their sampling, teaching interventions, and measurement methodologies. **A systematic evaluation of teaching efficacy is necessary for the creation of data-driven teaching plans that adequately support student learning.** These findings are supported by the lingering questions of Putnam et al. [100]:

> *"We present three lingering questions. . . (1) approaches to incorporate accessible topics; (2) sharing course resources; and (3) concerns about assessment, that is, sharing ideas about incorporating 'authentic assessment', and how to assess the efficacy of varied approaches to teaching accessibility." [100]*

We still do not know which teaching methods are most effective for supporting students' learning in accessibility. Current literature has laid the foundation for possible outcomes that can be observed but it is unclear how to best equip students with accessibility expertise.

One possible method for supporting an evidence-based curriculum design is to systematically assess the teaching condition effects on students' accessibility ***knowledge, awareness, and attitudes***. In this dissertation, we systematically analyzed four teaching ***conditions***: *lectures, projects on accessibility, interaction with a stakeholder/end user with a disability*. The fourth ***condition***,[2] *collaboration with a team member with a disability*, often occurred at RIT due to the university's focus on inclusive education. For instance, RIT has a large population of students who were deaf, hard of hearing, and who had autism, due to *The National Technical Institute for the Deaf* and the *Autism Spectrum Program*. The services provided by the university not only ensured a diverse student population, but also an inclusive approach to education.

[2] The four teaching conditions were designed by Huenerfauth et al. [54].

2.4 Existing Measures of Learning

Researchers have used measures of accessibility ***knowledge, awareness,*** and ***attitudes*** to understand students' comprehension, experiences, and motivations. In this section, we discuss measures instructors have used within and **outside** of computing.

2.4.1 Knowledge of Accessible Techniques

As discussed in Section 2.3, instructors used anecdotal summaries, observations, grades [20], and students' identification of accessibility barriers [41] to assess content knowledge. Carter and Fourney proposed an evaluation of computing students' written submissions of accessibility topics (refer to: section 2.3.3). However, the measurement was not evaluated due to a limited number of participants. Freire et al evaluated computing students' knowledge of web accessibility before and after use of a screen reader [41], but this approach may not be useful for students who already use a screen reader.

In order to overcome the limitations in existing measures, Huenerfauth et al. created a custom questionnaire that assessed students' ***knowledge*** of accessibility guidelines, programming techniques, and technology design considerations [54]. One set of questions outlined considerations for software design with items such as, *'Providing access to all elements of the user interface via keyboard commands'* and selection options of *'I'm familiar with this issue'* and *'I have taken this issue into account to make it more accessible for people with disabilities'*. The questionnaire provided an opportunity to assess knowledge through pre and post comprehension and was designed for the purposes of the NSF grant application related to this dissertation [54].

2.4.2 Awareness of Assistive Technologies

Prior researchers have assessed students' ***awareness*** of accessible technologies through questionnaires and scenarios. Ludi used a voting scenario questionnaire to implicitly measure students' interest in considering individuals with a disability during requirements gathering [77]. The first scenario by Ludi asked whether the New York Board of Elections representatives would be sufficient to gathering requirements for an electronic voting kiosk system [77]. Although the term *'sufficient'* may have led respondents to preemptively decide a more diverse population was necessary, the scenario purposely omitted the word *'accessibility'*. In the second scenario, respondents critiqued the use of a vertical low-fidelity prototype while eliciting requirements from Board of Election representatives. Both scenarios were scored dichotomously: students received a score of 1 if they mentioned accessibility and 0 if they did not [77].

In collaboration with Ludi, Palan et al [94] proposed a revised version of the voting scenario questions [77]. The first question asked respondents to outline considerations for a voting kiosk design while the second question asked respondents identify potential voters to recruit for requirements gathering [94]. The revised scenario questions did not use the term *'sufficient'*. Both questions were scored dichotomously, similar to with Ludi's original work [77].

Other questionnaires, such as the *Life Experiences Questionnaire* [105], could bias responses. For example, the questionnaire asked:

> *"What experiences in the last two years [have] most affected [your] thinking about social problems? (e.g., reading, making important decisions, new responsibilities, events in the world and nation, new friends, personal tragedy, etc.)" [105].*

In this question, participants were likely to incorrectly, or incompletely, recall information in the past (recall bias). The parenthetical examples could also lead respondents to an unnatural response (e.g., social desirability bias and leading questions).

Overall, Ludi's scenarios appropriately measure students accessibility ***awareness*** through indirect questionining. Huenerfauth et al used the revised version of Ludi's [94] scenario questions in addition to, custom questions regarding students' experiences with accessibility topics [54]. The custom accessibility ***awareness*** questions by Huenerfauth et al. [54] included questions of accessible technologies used by individuals who had low vision, deafness, blindness, a learning disability, among others (refer to: Appendix A, Chapter 4).

2.4.3 Attitudes towards Individuals with a Disability

Attitudinal questionnaires have been used by researchers to assess students' empathy and motivations for addressing accessibility barriers. One international measure for evaluating accessibility ***attitudes*** is the *Interactions with Disabled Persons Scale* (IDP) [17, 40, 122]. The IDP scale contains updated language from 1992 [45] and has been widely used throughout the world [17, 40, 116, 122, 128]. Although a subset of questions contain outdated language (e.g., non person-first language), Forlin et al.'s factor analysis reduces the number of outdated questions and aligns the 20

IDP questions with six ***attitude*** factors: *Discomfort, Sympathy, Uncertainty, Fear, Coping, and Vulnerability* [40] (refer to Table 2.1).

Alternate measures were not suitable for the purposes of this dissertation as they did not focus on accessibility [11, 19, 24, 31, 52, 53, 75, 88, 121, 142]. For instance, the *Toronto Empathy Questionnaire* measured an individuals' general empathy, but no questions were directly associated with accessibility [121]. Questionnaires for professional ethics [11, 30] did not focus on accessibility.

Alternate measures were also limited by the language used. An example of this was the Attitudes with Disabled Persons Scale (ATDP) [50] which had 93% of questions (n=28/30) without person-first language (e.g., *'Disabled workers can be as successful as other workers'*) [154]. The ATDP also referred to individuals who were not disabled as 'normal' in question 30:

> *"Most physically disabled persons have different personalities than normal persons" [50]*

Similarly, *Implicit Association Test* (IAT) used outdated language by contrasting *'abled persons'* and *'disabled persons'* [154]. Administering the IAT and ATDP survey could have resulted in polarized responses due to participants' identification of the outdated terms.

Table 2.1: Interactions with Disabled Scale (IDP) Sample Questions

Factor		Sample Question
Discomfort	Q11; 16-18	*I can't help staring at them*
Sympathy	Q1-3; 13	*I feel frustrated because I don't know how to help*
Uncertainty	Q1; 6; 9; 12	*I feel unsure because I don't know how to behave*
Fear	Q7; 20	*I am grateful that I do not have such a burden*
Coping	Q14; 15	*I don't pity them*
Vulnerability	Q4; 5	*I wonder how I would feel if I had a disability*

Note. The full survey is available in Appendix A

Due to the benefits of the IDP scale and strength of Forlin et al.'s factor analysis [40], we chose to use the IDP for analysis within this dissertation. An additional benefit of using the IDP scale was that external researchers could employ the survey in different languages [29], supporting future study replication. Additional discussion of the questionnaire and scoring methods will be discussed in Chapter 4.

2.5 Summary

The demand for accessibility-aware computing processionals is driven by ethical reasoning, market need, and government guidelines. Ethically, there is a motivation to ensure that all individuals can benefit from technology, as it pertains to health, social participation, political involvement, economic opportunities, and security [4, 149]. From a market perspective, accessible technologies have been found to fuel innovation, through their delivery of flexible inputs and outputs [70]. Accessibility-aware computing professionals are also needed to ensure that current and future technologies adhere to government regulations [71, 76, 143]. Within the past 20 years, new amendments to regulations have been enacted, ensuring that kiosk systems [137], websites [138], and mobile devices [133] are accessible to individuals with a disability. As regulation for compliance continues throughout the years 2016 to 2023, companies will begin to focus more on the creation of accessible technologies.

Although there is a demand for accessibility-aware computing professionals [67, 125], there is no requirement for universities to institute accessibility training within computing disciplines [2, 8, 56]. Current computing curricula, such as the ACM Joint Task Force Computing Curricula [56] and the Accreditation Board for Engineering [2], have begun to mention accessibility but no requirement is enforced [8]. Instructors that are aware of the need for accessibility in computing have incorporated content within their courses [16, 77, 141]. However, as discussed in Section 2.2.2, it remains unclear which teaching methods are most effective [100].

Chapter 3

Teaching Conditions for Accessibility Instruction

3.1 Introduction

In 2015, Huenerfauth, Hanson, and Ludi began a four-year initiative to evaluate the efficacy of different teaching ***conditions*** at Rochester Institute of Technology (RIT) [54]. Four teaching ***conditions***, described in Section 3.3, were integrated within two Human-Computer Interaction (HCI) courses that already taught accessibility: *Designing the User Experience (IT 260)* and *Human-Centered Requirements and Design (SE 444)*.

This chapter contains an overview of the two HCI courses from which data was gathered. As outlined in Table 3.1, the accessibility modules were included in both IT and SE HCI courses.

Table 3.1: Courses Sampled in this Dissertation

Course	**Degree**
Designing the User Experience	IT
Human-Centered Requirements and Design	SE

3.2 Accessibility Instruction at Rochester Institute of Technology

Designing the User Experience (IT 260) and *Human-Centered Requirements and Design (SE 444)* were required courses for SE and IT students. During both HCI courses, students experienced different ***conditions***: *lectures, team projects, stakeholders/end users with a disability, and team members with a disability* (refer to Chapter 1). The ***conditions*** were nested, whereby a student who collaborated with a team member with a disability also gained all three prior ***conditions***. As such, the order of the ***conditions*** was based on the number of teaching methods to be integrated within a course. Lectures required the least effort when compared to all other conditions.

This section discusses why accessibility education was integrated within HCI courses at RIT. The teaching ***conditions*** are also discussed in addition to students' curriculum.

3.2.1 Background: Benefits of Accessibility Modules

Researchers have indicated multiple benefits to including accessibility within broader HCI courses. Koppelman and Djik, found that when accessibility was incorporated within an HCI course, students were able to understand the importance of user evaluations [61]. When accessibility was not included in HCI courses, students designed software for users similar to themselves and relied on their personal experiences to inform the functionality of the system [61]. Petrie and Edwards noted similar observations [96]:

> *"Know thy users is a common motto in HCI, and many would add '...for they are not you'. No matter how well this message is conveyed to students, though, it usually does not extend to their realizing that users may be very different from them ... It is imperative that students learn an awareness of the needs of users with other characteristics, particularly disabled and elderly (potential) users of technologies and how to design and evaluate systems that meet these needs"*

Instructors have also found that incorporating accessibility within larger courses can establish the understanding among students that accessibility bolsters usability for all users [8, 99]. When accessibility was integrated within HCI [99] or web programming courses [108], it was not perceived as an isolated topic (refer to Chapter 2).

Incorporating accessibility within HCI courses was also pragmatic; no additional faculty or logistics were needed. Universities could simply integrate information within established courses. As Lazar explained [68]:

> *"It would be ideal for a university to teach a new course in information systems program on accessibility. Due to the nature of the course approval process and academic scheduling, it can take nearly a year or more to get a new course approved and included in the course schedule. In addition, many academic programs do not have space in their programs for a new course, nor the resources or faculty to teach such a course. Within these limitations, it seems best to incorporate the topic of accessibility into currently-existing courses in information systems." [68]*

When instructors created specialized courses they were less effective. As discussed in Chapter 2, these courses resulted in low enrollment since the holistic benefits of accessible technologies were not well known among students [10, 99]. As such, this dissertation examines the efficacy of accessibility instruction within two required HCI courses for IT and SE students at RIT: *Designing the User Experience* and *Human-Centered Requirements and Design*, as will be discussed next.

3.2.2 Designing the User Experience

Designing the User Experience was a required course for undergraduate IT students. IT students enrolled in the course during their second or third year of study. The duration of the *Designing the User Experience* course was one semester (14 weeks). Throughout seven semesters from spring 2015 to 2019, student enrollment averaged 40 students per semester (n=277).

As outlined in Table 3.2 *Designing the User Experience* focused on user-centered design principles. Students learned usability heuristics, requirements gathering, and software testing. During the course, students completed a team project while considering the complete development lifecycle.

Adjacent Courses in Information Technology Curriculum

Prior to *Designing the User Experience*, IT students completed courses in object oriented programming languages, discrete mathematics, database modeling, and web and mobile development methods. During the second-year of study, students furthered their knowledge of databases, software design principles, and mobile development (refer to: Appendix I).

3.2.3 Human-Centered Requirements and Design

Software Engineering (SE) students enrolled in *Human-Centered Requirements and Design* during the third-year of their degrees. From spring 2015 to 2019, student enrollment averaged 51 students per semester (n=356). As outlined in Table 3.2, the *Human-Centered Requirements and Design* also focused on user-centered software development processes. During the course, students worked in teams to design software systems that maximized the usability for target users.

Similarly to *Designing the User Experience*, project reports, presentations, and questionnaires (pre and post) were collected from students (refer to: Chapter 5).

Adjacent Courses in Software Engineering Curriculum

Prior to taking the *Human-Centered Requirements and Design* course, SE students completed courses in calculus, discrete mathematics, object oriented programming, physics, and statistics. During the *Human-Centered*

Requirements and Design course students took algorithm analysis and math and science electives. While IT and SE students learned similar computing topics, the level of detail differed between both curricula. SE students' full curriculum is included in Appendix I.

3.3 Teaching Conditions & Artifacts

The ***conditions*** were determined by the instructor and their plans for the course; they were not assigned by the researchers. All ***condition*** artifacts were provided to instructors at the start of the semester (e.g., *content lectures and sample projects*). In this section, we discuss the teaching ***conditions*** applied at RIT.

Table 3.2: Computing Courses with Accessibility Modules

Course	Weekly Hours	Discipline	Degree Level	Course Description
Designing the User Experience	3	Information Technology	2	The user experience is an important design element in the development of interactive systems. This course presents the foundations of user-centered design principles within the context of human-computer interaction (HCI). Students will explore and practice HCI methods that span the development lifecycle from requirements analysis and creating the product/service vision through system prototyping and usability testing. Leading edge interface technologies are examined. Group-based exercises and design projects are required.
Human-Centered Requirements and Design	3	Software Engineering	3	This course introduces quantitative models and techniques of human-computer interface analysis, design and evaluation, which are relevant to the software engineering approach of software development. User-focused requirements engineering topics are also covered. Contemporary human computer interaction (HCI) techniques are surveyed, with a focus on when and where they are applicable in the software development process. Students will deliver usable software systems derived from an engineering approach to the application of scientific theory and modeling. Other topics may include usability evaluation design, methods of evaluation, data analysis, social and ethical impacts of usability, prototyping and tools.

3.3.1 Lectures

A **week-long** series of accessibility lectures were provided to instructors discussing: the diversity of human abilities, the need for accessible technologies, and the prevalence of disability. The lectures also included information on international guidelines, U.S. legal requirements, and disability etiquette to better prepare students for the workforce. Appropriate accessibility-related terms, such as the difference between 'deaf' and 'Deaf', were included to prepare students for software requirements elicitation. As outlined in Table 3.3, the accessibility lecture content was organized within three presentations. All lecture content was consistent with prior researchers' suggestions [77, 96, 108].

The lecture content was presented with text, images, and simulations to depict how software designs were perceived by diverse users. Figure 3.1 includes two sample slides depicting how technology would be perceived by individuals with glaucoma and macular degeneration. Appendix D includes all slides.

Prior studies on computing education have found that students report lectures being particularly useful in introductory courses [51, 85, 89]. Lectures

Table 3.3: Content within the Accessibility Lectures, as Suggested by Prior Researchers

Lecture	Content	Related Work
01 Abilities and Sense	Physiology and simulation of how users perceive technology	[108,140,141,153]
01 Abilities and Sense	Appropriate terms	[77]
01 Abilities and Sense	Measures of a disability (e.g. visual acuity, decibels)	[140]
01 Abilities and Sense	Prevalence of disability	[96, 99]
02 Technology Laws	U.S. regulations on accessible technologies, international guidelines	[96, 108, 141, 153]
03 Web Accessibility	Accessibility principles (POUR)	[152]
03 Web Accessibility	HTML markup (alt text, headers, keyboard navigation) and CSS	[109, 141, 153]
03 Web Accessibility	How to create proper alt tags and captions	[141, 153]
03 Web Accessibility	Accessible PDFs and presentations	[141]
03 Web Accessibility	Event handlers (e.g., onMouseOver)	[109, 141, 153]

allowed students to ask clarifying questions and it prepared them for hands-on assignments [51].

3.3.2 Projects on Accessibility

The second condition included projects on accessibility which spanned the duration of the course. A sample report outline was provided to instructors

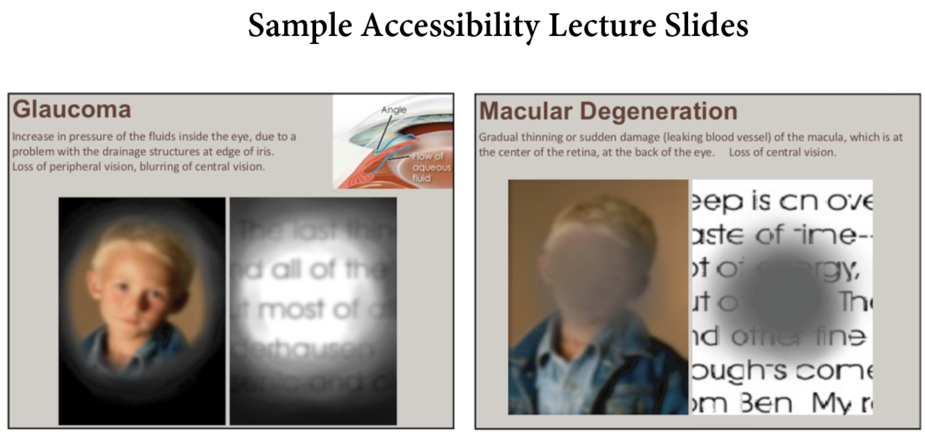


Figure 3.1: Sample slide simulating how software content in the central vision of individuals with glaucoma is most accessible. On the other hand, software content in the peripheral vision is most accessible for individuals with macular degeneration.

at the start of each semester (Appendix E), which required students to justify their target users and design decisions through usability research. Student deliverables were collected directly from instructors at the end of each semester.

Prior studies have found that when students completed team projects, they experienced the complexity of real-world systems [16, 97, 139]. Team projects also strengthened students' time management skills [81, 139].

3.3.3 Stakeholders or End Users with a Disability

The third condition included interactions with a stakeholder. Instructors who were interested in collaborating with local organizations had the opportunity to partner with *Association for the Blind and Visually Impaired*, *CP Rochester*, and *Al Sigl*, which were all in Rochester, NY. In addition, students had the opportunity to connect with peers in the *Access Services Program*, *National Technical Institute for the Deaf*, and the *Autism Spectrum Support Program*, which were all part of Rochester Institute of Technology.

In prior studies, students identified accessibility errors in their projects after collaborating with stakeholders or end users who had a disability [64, 77, 117]. Although exposure to individuals with disabilities appeared to be a promising teaching strategy for increasing awareness of accessibility [16, 64, 77, 117], it required thorough planning by instructors and monetary resources for stakeholder compensation. Quantifying the impact of students' exposure to individuals with a disability was necessary in order to justify university course budgets and priorities.

3.3.4 Team Member with a Disability

The final condition involved direct collaboration with a team member. This final ***condition*** required the most effort from instructors as students must have also received all prior ***conditions*** (*content lectures, projects on accessibility, stakeholder/end user with a disability*). RIT's focus on inclusive education facilitated student collaboration through its' note taking, American Sign Language interpreting, and other services.

Prior studies found that when students were exposed to end users or stakeholders with a disability, they readily identified accessibility barriers and considered designs to overcome them [77, 117]. Therefore, it was possible that direct collaboration with team members have elevated these observations, providing additional instances to increase students' ***awareness*** and ***knowledge*** of accessibility.

3.4 Summary

The four-year NSF research project at Rochester Institute of Technology was the focus for a comparative analysis of the teaching ***conditions***. Four teaching ***conditions*** were studied: *accessibility lectures, projects, stakeholders with a* *disability, and collaboration with team members who have a disability*, which were consistent with previously suggested teaching strategies [16,20,64,77,140] but had yet to be formally compared. The data collected from both IT and SE courses is further described in Chapter 4 and 9.

Chapter 4

Questionnaire Measurements

4.1 Introduction

This chapter provides an overview of the questionnaire measurements used to estimate students' ***knowledge*** of accessibility implementation techniques, ***awareness*** of assistive technologies, and ***attitudes*** towards individuals with a disability. The questionnaire was informed by a review of existing measures used within and outside of computing disciplines (refer to Chapter 3). The survey contained a total of 60 questions separated within 13 sections [54].

As outlined in Table 4.1, ten of the 13 sections were custom-made to assess students' learning. These sections inquired about students' involvement in the development of accessible technologies and their awareness of implementation techniques. The remaining three sections included the revised version [94] of

Table 4.1: Pre/Post Survey Questions

No.	Type	Content
1	Background	Name*
2	Background	Email*
3	Open-ended	Voting Scenario [77]
4	Open-ended	Voting Scenario [77]
5	IDP Scale	20 IDP questions (*Range: Agree very much - Disagree very much)*
6	Open-ended	Optional comments on the IDP scale*
7	Accessibility awareness	8 Accessibility awareness sub-questions *(Range: I have knowledge of this - I have personal experience with this)**
8	Open-ended	Optional comments on the awareness questions(
9	Web design accessibility knowledge	8 Web design accessibility knowledge sub-questions *(Range: I have heard or read about this - I have done this before)**
10	Web programming accessibility knowledge	10 Web programming accessibility knowledge sub-questions *(Range: I am familiar with this issue - I have taking this issue into account to make the site more accessible to people with disabilities)**
11	Software accessibility knowledge	6 Software accessibility knowledge sub-questions *(Range: I am familiar with this issue - I have taking this issue into account to make it more accessible to people with disabilities)*
12	Yes/No	Involvement with design/development*
13	Yes/No	Consideration of diverse users in prior work*

Note. Asterisk (*) denotes custom section. Full survey is available in Appendix A

Ludi's [2007] [77] voting scenario questions and the Interactions with Disabled Persons scale (IDP) questions [45]. The following sections of this chapter will discuss each part of the survey in detail.

4.2 Knowledge of Accessible Implementation Techniques

A total of 26 questions contained within three sections (Numbers 9-11 in Table 4.1) were used to assess students' ***knowledge*** of accessible programming techniques. As discussed in Chapter 2, Huenerfauth et al. [2015] developed the ***knowledge*** questionnaire to provide a systematic evaluation of students' overall learning across software, systems, and web technologies [54]. The questions were consistent with the software design recommendations of the Section 508 of the Americans with Disabilities Act [131] and the international Web Content Accessibility Guidelines [150]. **Higher *knowledge* scores implied greater familiarity with accessibility implementation techniques.**

4.2.1 Web Design

The ***knowledge*** questions began with eight web design items. The overall question stated, *'I know how to design websites and software to ensure that* *it is accessible for the following people'* with eight items delineating different populations (e.g., individuals with low vision, autism, learning disabilities, among others). Responses of *'I have heard or read about this'* were scored as 1 and *'I have done this before'* were scored as 2. It was assumed that students with experience applying web design concepts would be more ***knowledgeable*** of the content.

4.2.2 Web Programming

Next, students were asked ten web programming questions regarding CSS and HTML. The overall question stated, *'I understand how the following aspects of website design affect people with disabilities'* with ten items of considerations. The ten items included the considerations of alt text, table headings, underlined hyperlinks, captions, and color usage. All ten considerations were outlined in the Web Content Accessibility Guidelines [150]. Responses of *'I'm familiar with this issue'* were scored as 1 and *'I have taken this issue into account to make sites more accessible for people with disabilities'* were scored as 2. Similarly to the web design questions, it was assumed that students who applied web programming practices would be more ***knowledgeable*** of the content. Many of the web programming questions items required minimal effort by students, such as adding alt tags to images.

4.2.3 Software Implementation

Next, students were asked six software accessibility questions. The overall question stated *'I understand how the following aspects of software or mobile-app design affect people with disabilities'* with six items of considerations. The six items included considerations for accessible technology compatibility, magnification of graphics, multi-modal content, and fixed time limit responses that were outlined in Section 508 of the Americans with Disabilities Act [131]. Responses of *'I'm familiar with this issue'* were scored as 1 and *'I have taken this issue into account to make sites more accessible for people with disabilities'* were scored as 2.

4.2.4 Close-ended Questions

Lastly, two close-ended questions inquired on students' prior technical experiences with accessibility. The first question asked whether students had previously been involved in the design or development of software or websites. The second question asked whether students had worked on the design or development of a software or website that considered individuals with diverse abilities. Responses with *'Yes'* were scored as 1 and *'No'* were scored as 0.

4.2.5 Composite Knowledge Score

All 26 ***knowledge*** questions *(score range=0-50)* were averaged to obtain a composite knowledge score. The higher the knowledge composite score, the more familiarity a student had gained with accessibility implementation techniques in web design, web programming, and software.

4.3 Awareness of Assistive Technologies

Students' ***awareness*** of accessible technologies was assessed through eight questions. **Higher scores indicated greater *awareness* of the assistive technologies.**

The questionnaire by Huenerfauth et al [2015] [54] overcame the limitations in related work by focusing on accessibility and its implications to technology (refer to Chapter 2). By asking direct questions about accessibility, the questions by Huenerfauth et al [2015] [54] ensured students had the opportunity to showcase their awareness.

4.3.1 Awareness Questions

Eight questions (Number 7 in Table 4.1), were used to identify students' ***awareness*** of accessible technologies as used by: *individuals with low vision, blindness, deaf or hard of hearing, autism, learning disabilities, intellectual disabilities, motor or movement disabilities, and older people.* Responses of *'I have knowledge of this'* were scored as 1 and *'I have personal experience with this'* were scored as 2. Students with secondary sources of knowledge (e.g., article, book, lecture) were assumed to have less ***awareness*** of assistive technology.

4.3.2 Composite Awareness Score

The eight ***awareness*** questions *(score range=0-16)* were averaged to obtain a composite score. High composite scores indicated greater ***awareness*** of assistive technologies.

4.4 Voting Scenario Questions

The revised voting scenario questions [94] by Ludi 2007 [77] were used to assess students' interest in considering the needs and preferences of individuals with disabilities (Numbers 3-4 in Table 4.1). While these scenario questions did not contribute to students' ***awareness, knowledge,*** nor ***attitude*** scores, they did provide context for students' responses. **Higher scores on the voting scenario questions indicated greater consideration of end users.**

The first voting scenario asked about key design considerations for a voting kiosk, while the second question asked what potential voters would test the prototype. If a response mentioned accessibility, it was scored as 1, otherwise it was scored as 0. One benefit to the voting scenario questions, as discussed in Chapter 2, was that the scenarios implicitly assessed students' interest in accessibility requirements. As such, the voting scenario questions were the first two questions provided to respondents (Refer to Table 4.1).

4.4.1 Composite Voting Scenario Score

The voting scenario questions *(range=0-2)* were averaged to obtain a composite score. Higher composite scores indicated a greater consideration of individuals with a disability.

4.5 Attitudes towards Individuals with a Disability

Attitudes were estimated with the Interactions with Disabled Persons Scale (IDP) [45] (No. 5 in Table 4.1). As discussed in Chapter 2, the IDP scale focused on accessibility and was more appropriate than alternate measures. Seventeen out of 20 questions were scored in descending order from *agree very much (score=6)* to *disagree very much (score=1)*. Three negatively worded questions were reverse scored (Q10, 14-15) [40].

The questions were grouped into six ***attitude*** factors: *discomfort, sympathy, uncertainty, fear, coping, and vulnerability* [40]. As outlined in Table 4.2, three out of 20 questions were not used to determine ***attitude*** scores (Q8,10,19), following the suggested model of Forlin [1991] [40]. **Higher scores on the IDP scale indicated a lack of ease when interacting with individuals with a disability.**

Table 4.2: Six Factors of the Interactions with Disabled Persons Scale

Factor Name	**Questions**
Discomfort	Q11, 16-18
Sympathy	Q1-3, 13
Uncertainty	Q6, 9, 12
Fear	Q7, 20
Coping	Q14, 15
Vulnerability	Q4, 5

4.5.1 Discomfort with Individuals with a Disability

The level of ones' discomfort with individuals with a disability was measured through four IDP questions *(Q11,16,17,18)*. No questions were reverse-scored and higher values indicated greater discomfort when interacting with individuals with a disability. Question 11 stated, *'I am afraid to look at the person straight in the face'*, with six Likert-scale options of *agree very much (score=6)* to *disagree very much (score=1)*. A respondents' discomfort score was calculated through the average of the four questions *(Q11,16,17,18)*.

4.5.2 Sympathy towards Individuals with a Disability

Sympathy towards an individual with a disability was measured with four IDP questions *(Q1, 2, 3, 13)*. Students who selected *agree very much* to statements such as question 13, *'I admire their ability to cope'* received a score of 6 points. The final sympathy score was gathered by calculating the average of the four questions *(Q1, 2, 3, 13)*.

4.5.3 Uncertainty towards Disability

Uncertainty towards disability was measured with three IDP questions *(Q6, 9, 12)*. Uncertainty questions, such as question 6, *'I feel unsure because I don't* *know how to behave'* indicated higher levels of apprehension when interacting with individuals with a disability. The two response answers were averaged to obtain a final uncertainty score.

4.5.4 Fear of a Disability

Fear of a disability was measured with two IDP questions *(Q7, 20)*. Question 20 states, *'I dread the thought that I could eventually end up like them'* where higher average scores indicated greater fear of a disability.

4.5.5 Coping with a Disability

Coping with a disability was measured through two IDP questions *(Q14, 15)*. **Both questions were reverse-scored**, following the model of Forlin [1999] [40], as generally the IDP questions measured a lack of ease when interacting with individuals with a disability. Positively worded statements such as question 15, *'After frequent contact, I find I just notice the person not the disability'*, were reverse scored. In this way, the coping scale was consistent with all other IDP factors, where higher average scores indicated an overall discomfort when interacting with individuals with a disability.

4.5.6 Vulnerability of a Disability

An individuals' vulnerability of a disability was measured through two IDP questions *(Q4, 5)*. Students who selected *agree very much* to statements such as question 4, *'Contact with a disabled person reminds me of my own vulnerability'* received a score of 6 points.

4.6 Summary

The accessibility questionnaire designed by Huenerfauth et al. [2015] [54], included measures of students' ***knowledge*** of accessible implementation techniques, ***awareness*** of assistive technologies, and ***attitudes*** towards individuals with a disability (Refer to: Appendix A). The questions for each measure were compiled into nine composite scores (***knowledge, awareness, voting scenario, and 6 attitude IDP factors***). The composite scores were used for analysis as they summarized each measure holistically. For instance, the composite ***knowledge*** score considered students' responses to the implementation considerations for website programming, website content, and software design. Chapter 5 of this dissertation provides an overview of the recruitment methods and the power estimations for analysis.

Chapter 5

Collection of Questionnaires

5.1 Introduction

We assessed undergraduate Information Technology (IT) and Software Engineering (SE) students' learning (***knowledge, awareness,*** and ***attitudes***) throughout spring 2016 to spring 2019. This chapter outlines the methods for participant recruitment, survey data collection, and analysis. All collection processes were approved by the RIT Institutional Review Board (Refer to: Appendix B). Survey participants were recruited for a voluntary questionnaire described in Chapter 4. As seen in Figure 5.1, the timing and duration of recruitment varied; IT and SE students in the target courses (generally 2nd or 3rd year) were recruited twice per semester, while senior-level students were recruited throughout the academic year.

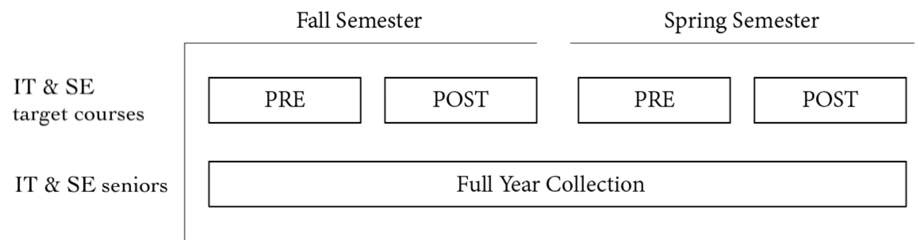


Figure 5.1: Recruitment intervals vary by year level. Information Technology (IT) and Software Engineering (SE) students were recruited twice per semester (pre and post), while senior level students were recruited throughout the academic year.

5.2 Targeted Courses: Information Technology and Software Engineering

Information Technology (IT) and Software Engineering (SE) students enrolled in *Designing the User Experience (IT 260)* and *Human-Centered Requirements and Design (SE 444)* were surveyed at the start (pre) and end (post) of each semester. Questionnaire responses were collected from students twice during the semester to measure learning effects from different ***conditions***. During each round of recruitment (pre and post) students had the opportunity to win a $100 raffle. Both the pre and post questionnaires were identical and took approximately 10-15 minutes to complete (Refer to: Chapter 4). Project reports were also collected from students enrolled in the IT and SE courses.

5.2.1 Identification of Students' Conditions

At the end of the semester, instructors indicated which ***conditions*** students received. Five questions were posed to instructors (refer to: Table 5.1), allowing them to delineate each student and their teaching ***conditions***. The teaching ***conditions*** could vary by student teams; not all teams contained a team member or stakeholder with a disability, for example. As previously outlined in Table 1.1, the ***conditions*** were nested, whereby a student in the *end user* condition must have also had exposure to *lectures* and *projects*. A student in the *end user* ***condition*** would have had all three ***conditions*** marked by the instructor.

Table 5.1: Possible Teaching Conditions for IT and SE students

	Question	**Condition label**
1.	*Did the course include a week of lectures about disabilities or accessibility?*	Lectures
2.	*Did this project relate to the topic of accessibility or were students asked to consider people with disabilities as part of their project?*	Project
3.	*Did the team meet or interact with someone with a disability, e.g. to get requirements for the project?*	End user
4.	*Was one of the members of the team a person with an apparent disability?*	Team member

5.2.2 Data Collection Methods

Students were recruited to participate in the questionnaires through announcements, course websites, emails, and flyers. At the start of the semester, flyers were distributed throughout the college. Follow-up emails and course website announcements were used to remind students of the questionnaire before raffle winners were selected. This process was repeated during the last weeks of the semester for post data collection.

During years 2016-2018, two raffles ($100 each, *total*=$200) were distributed each semester at the pre and post intervals. During the academic year of 2018-2019, a $100 gift card was raffled for each section of the HCI course. Incentives for participation were changed in 2018, in order to encourage more students to participate in the study.

All efforts were made to ensure students understood that the questionnaire was voluntary and that participation had no impact on their course grade. For instance, the questionnaire mentioned, *"...The purpose of this survey is to help us understand students' awareness of the needs of users in technology. This voluntary survey is confidential and will not affect your course [grade]."*

5.2.3 Sample Size for Analysis: Power Estimation

To calculate the necessary survey sample size, we referred to Fitchen et al.'s prior work (M_{change}=4.07, SD = 11.51). A paired t-test power analysis (via R *pwr* package [23]) indicated that significant IDP paired differences (pre and post) could be observed with 65 participants. Therefore, a minimum of 65 paired responses were required within the ***conditions*** of *stakeholder/end user with a disability* and *collaboration with a team member with a disability.* As discussed in Chapter 4, power estimations for accessibility ***knowledge*** and ***awareness*** questions could not be determined from prior work as they had been custom-made for this study.

5.2.4 Response Rates

A total of 315 paired (pre and post) questionnaire responses were collected from students throughout spring 2016 to 2019 (47.5%, 315/663), where our minimum sample size requirements from the power analysis were met for all IDP measures (refer to: Appendix G). The unpaired response rate during this time was 71.6% (n=475/663), exceeding typical organizational and educational survey research response rates [6].

5.3 Senior-Level Information Technology and Software Engineering Students

One-time questionnaire responses were also collected from senior IT and SE students who completed the accessibility instruction 12-18 months prior. Senior-level students *did not* receive repeated exposure to the teaching ***conditions***. The purpose of the longitudinal analysis was to evaluate how much information students retained 12-18 months after instruction.

5.3.1 Data Collection Methods

Questionnaire responses were collected through in-class announcements, emails, and flyers. Class announcements were made during two required courses, *Senior Development Project II & II (IT 500) and Software Engineering Project I & II (SE 561).* Senior students that completed the questionnaire received $20 for participation.

5.3.2 Sample Size for Analysis

For senior-level paired analysis, we approximated sample size was based on the total eligible sample size. From spring 2016 to 2017, a total of 166 pre responses were collected from students enrolled in the HCI courses and approximately

99 of these students[1] were eligible for graduation in the academic terms of 2017-2018 and 2018-2019. The actual number of participants who were eligible for graduation 12-18 months after taking the HCI course was likely less than 99 students, however the university could not disclose this information due to privacy and confidentiality policies.

Based on Cochran's formula for finite populations, 65-79 questionnaire responses could represent the sample (n=99) with a 95% confidence level and 5-7% margin of error. By analyzing results based on cohorts of seniors, we were able to control confounds, such as the introduction of elective accessibility courses after Spring 2017.

5.3.3 Response Rates

A total of 65 paired senior questionnaire responses (pre and senior) were collected during two academic years (2017-2018 and 2018-2019). This represents a conservative response rate of 65.7% (65/99).

[1] At RIT, 70% of students complete their undergraduate computing degrees within **eight years** [135]. Therefore, we conservatively estimate that 60% of students may complete their degrees within the scheduled four to five years.

Chapter 6

Cross Sectional Evaluation of Efficacy with Questionnaires

6.1 Introduction

This chapter contains a cross-sectional study of students' learning (spring 2016-2019) based on four conditions: *content lectures, projects on accessibility, exposure to a stakeholder/end user, and team member with a disability*. A subset of the data described in this chapter was previously analyzed based on *exposure* and *no exposure* groupings[1], where it was found that students who had exposure to an individual with a disability (via interactions with a *stakeholder/end user or team member*) gained more prosocial sympathetic attitudes when compared to students who did not have

[1]The work included in this chapter was previously published at ACM Special Interest Group in Computer Science Education (ACM SIGCSE 2018)

these experiences (*lectures or projects*). The analysis outlined in this chapter allowed us to differentiate the exposure conditions of *stakeholder/end user and team member with a disability* to identify whether one or both conditions contributed to students' prosocial sympathetic attitudes.

6.1.1 Research Question

The research questions addressed in this cross-sectional analysis were:

RQ 1. Do the four teaching conditions (*lectures, team projects, stakeholders/end users, and team members*) contribute to statistically significant changes in students' **short term** learning?

- **RQ 1.1.** Do students in the four teaching conditions report significantly different **knowledge of accessibility implementation methods**?
- **RQ 1.2.** Do students in the four teaching conditions report significantly different **awareness of accessible technologies**?
- **RQ 1.3.** Do students in the four teaching conditions report significantly different **attitudes towards individuals with a disability**?

6.1.2 Hypothesis

Based on related work that identified the benefits of interacting with an individual with a disability [14, 16, 77, 117], it was hypothesized that students who gained exposure to a *stakeholder or end user with a disability* would gain significantly higher accessibility ***knowledge***, ***awareness***, and ***attitudes*** in the short-term. Although studies did not include significance testing [14, 16, 77, 117], the findings suggested that these experiences led to increased empathy [14] and awareness of diversity [16].

6.2 Methods

As discussed in Chapter 5, Information Technology (IT) and Software Engineering (SE) students were recruited through in-class announcements, course websites, emails, and flyers. Questionnaire responses were collected at the start (pre) and end (post) of the semester to determine changes in students' learning.

During seven semesters (spring 2016-2019), there were a total of fourteen courses with 663 students enrolled. During this time, 315 students completed both the pre and post questionnaire (*response rate*=47.5%). All questions were voluntary and as such, the number of responses per question could vary.

To determine the differences between the ***conditions***, we compared students' pre and post scores through 36 Wilcoxon Signed Rank tests. Normality was tested through the Shapiro-Wilk test. Individual tests were conducted for the nine ***measures*** and four possible ***conditions***. The nine ***measures*** included ***knowledge, awareness, voting scenario questions***, and ***six IDP attitudinal factors***.

To determine whether one condition contributed to significantly higher responses than another, we compared the composite change scores for each measure. The composite change score was calculated by subtracting the post score from the pre for each of the participants. Differences between the conditions were measured through a Mann-Whitney U test or Kruskal-Wallis H test, depending on the number of conditions that yielded significant results in the Wilcoxon Signed Rank test.

6.3 Results

Our hypothesis was that interactions with a stakeholder or end user would yield significant differences in all the composite scores. Furthermore, we assumed that any significant differences observed for the *stakeholder* ***condition*** would also be found in the *team member* ***condition*** due to the nature of the stacked conditions. However, we were surprised to find that when comparing the pre and post responses per condition and per measure, there were instances when significant differences were not sustained in the stacked conditions. For instance, students who had a *stakeholder with a disability* obtained more prosocial sympathetic attitudes, but this effect did not persist for the *team member* condition.

An overview of the instructors and ***conditions*** is available on Table 6.1. While not all professors taught the same number of course sections, the questionnaire responses were generally distributed among different instructors. The only exception to this was the *team member* and *stakeholder* condition, which had a large proportion of responses from one instructor. Since this project was conducted within the context of computing courses that were naturally offered at the university, the number of students enrolled each term in each course was out of our control. For instance, department chairs determined which professors would be assigned to particular sections of the courses each semester. In addition, we did not have control over the number of students with apparent disabilities who enrolled in each section of a course (the enrollment of students would thereby influence the team member condition). For these various practical reasons, a limitation of our study is that the number of students who experience various interventions was not completely balanced across all individual instructors and conditions.

Table 6.1: Number of Responses by Condition and Instructor

Instructor	Lectures	Projects	Stakeholder	Team Member
A	5 (7.4%)	13 (14.9%)	0 (0%)	0 (0%)
B	3 (4.4%)	12 (13.8%)	4 (4.26%)	17 (25.8%)
C	12 (17.7%)	21 (24.1%)	17 (18.1%)	27 (40.9%)
D	15 (22.1%)	27 (31.03%)	55 (58.5%)	6 (9.1%)
E	18 (26.5%)	12 (13.8%)	0 (0%)	8 (12.1%)
F	6 (8.8%)	0 (0%)	15 (15.96%)	7 (10.6%)
G	9 (13.2%)	2 (2.3%)	3 (3.2%)	1 (1.5%)

We did find however, that students in all ***conditions*** gained an increased *knowledge* of accessibility programming techniques. Table 6.2 contains a summary of all measures that yielded significant results. These results will be discussed in more detail within the subsections below. Comparisons between conditions, indicated that there was no condition that contributed to significantly different results. As seen in Figure 6.1, students' scores were centered in similar locations. The subsections below detail the corresponding IQR and test statistic values for each of the *p-values* in Table 6.2.

Table 6.2: Summary Wilcoxon Signed Rank Test *p-values* for all Knowledge, Awareness, and Attitude Measures based on each Condition

	Lectures	**Projects**	**Stakeholder**	**Team Member**
Voting	<0.001*	0.001*	0.004*	0.446
Sympathy	0.470	0.118	0.043*	0.096
Vulnerability	0.560	0.555	0.695	0.348
Fear	0.597	0.244	0.879	0.335
Uncertainty	0.248	0.621	0.752	0.639
Coping	0.033*	0.927	0.797	0.671
Discomfort	0.646	0.671	0.509	0.208
Awareness	0.228	0.014*	0.014*	0.846
Knowledge	0.003*	<0.001*	<0.001*	<0.001*

Note. Asterisk (*) denotes significance at α=0.05, two-tailed.

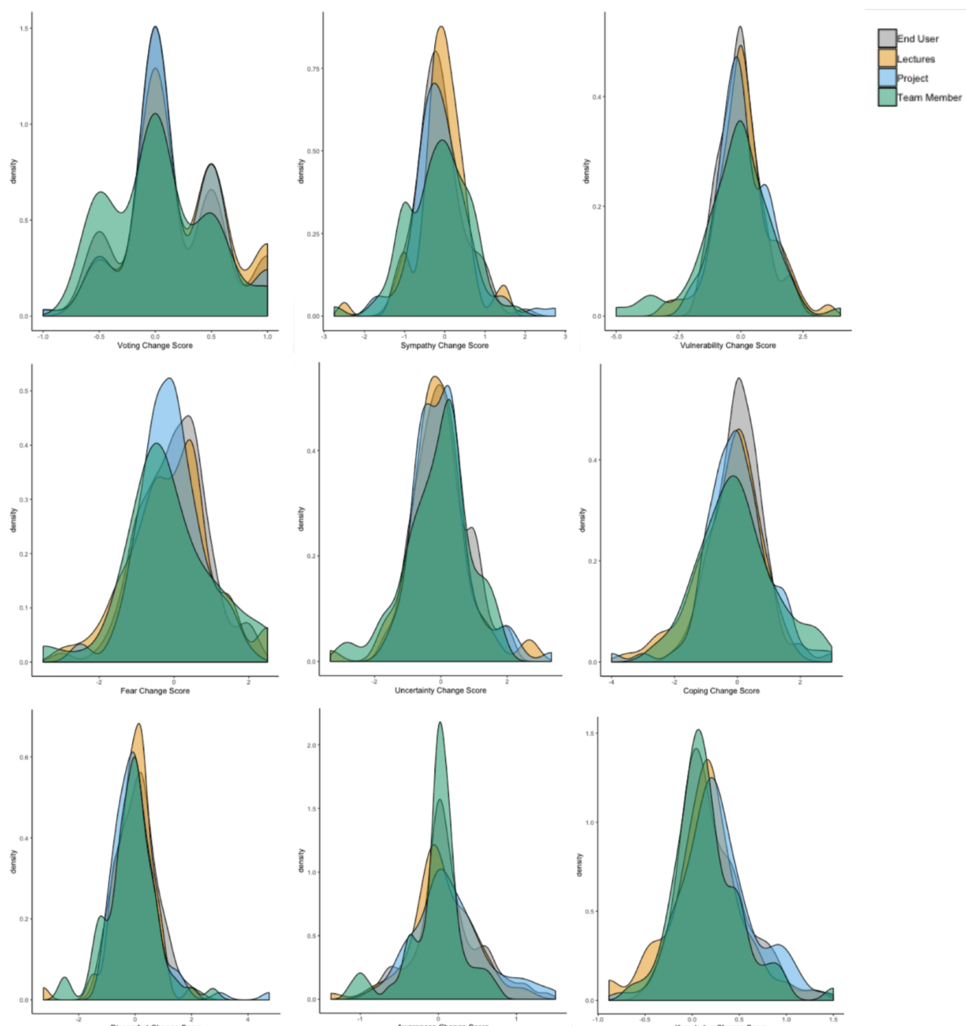


Figure 6.1: Distribution of Composite Change Scores (*post-pre*) by Measure and Condition

6.3.1 Voting Scenario Questions

As discussed in Chapter 4, the voting scenario questions were scored dichotomously depending on whether students considered accessibility within their response.

Comparing Pre and Post Scores

We observed a significant difference between the pre and post voting scenario scores for students in the *lectures, project, and stakeholder* condition (α=0.05). As shown in Table 6.3, students more frequently considered individuals with a disability when prompted with the voting scenario question at the end of the semester. There was no significant difference for students in the *team member* condition, where the pre and post score distributions were approximately equal.

Note that as previously noted, the p-values presented in Table 6.3 correspond to the top row p-values shown in the summary Table 6.2. This also holds true for p-values shown in later tables of this chapter which have been previously summarized in Table 6.2.

Table 6.3: Wilcoxon Signed Rank Test Results for the Voting Scenario Question Comparing Pre and Post Responses (Two-Tailed)

	No. Part.	Pre Mdn (IQR)	Post Mdn (IQR)	z	p-value
Lectures	66	0 (0.5)	0.5 (0.5)	-3.63	<0.001*
Project	84	0.25 (0.5)	0.5 (1)	-3.02	0.001*
Stakeholder	94	0 (0.5)	0.5 (0.5)	-2.63	0.004*
Team Member	63	0 (0.5)	0 (0.5)	-0.136	0.446

Note. Asterisk (*) denotes significance at α=0.05, two-tailed.

Comparison Between Conditions

To identify whether the teaching conditions led to significant differences in students' change scores, we conducted a Kruskal Wallis H test. There was no significant difference between the voting scores of students in the *lectures, project,* and *stakeholder* conditions ($X^2(2)$=1.913, p=0.384). This can be observed in Table 6.3, whereby the pre and post medians and inter-quartile ranges for the conditions were very similar.

6.3.2 Awareness of Accessible Technologies

Students' ***awareness*** of accessible technologies was assessed through eight questions on technologies used by individuals with a disability (refer to: Chapter 4). Students received a score of 0 to 2 for each question.

Comparing Pre and Post Scores

On the awareness questions, only students who completed a *project* on accessibility or had a *stakeholder* with a disability, obtained significantly higher scores on the post interval. The range of scores for students in the *project* condition, for example, was greater at the pre collection (*range*=0.125-1.875) than the post (*range*=0.375-2).

Students in the *stakeholder* condition had a smaller interquartile range at the post interval (*IQR*=0.375) than the pre (*IQR*=0.594). That is, post scores for students in the *stakeholder* condition were clustered around the median. In general, both students in the *project* and *stakeholder* condition indicated significantly greater awareness of accessible technologies at the post collection period. The medians and interquartile ranges for all the conditions are included in Table 6.4.

Table 6.4: Wilcoxon Signed Rank Test Results for the Awareness Questions Comparing Pre and Post Responses (Two-Tailed)

	No. Part.	**Pre Mdn (IQR)**	**Post Mdn (IQR)**	***z***	**p-value**
Lectures	62	1.12 (0.375)	1.12 (0.375)	-0.745	0.228
Project	83	1.12 (0.312)	1.12 (0.5)	-2.20	0.014*
Stakeholder	90	1.12 (0.594)	1.12 (0.375)	-2.21	0.014*
Team Member	65	1.12 (0.375)	1.12 (0.375)	1.02	0.846

Note. Asterisk (*) denotes significance at α=0.05, two-tailed.

Comparison Between Conditions

We did not observe a significant difference in the pre and post distribution scores of students in the *project* and *stakeholder* conditions for the awareness questions (U=3820, p=0.795, r=0.062, two tailed).

6.3.3 Knowledge of Accessible Technologies

The ***knowledge*** questions inquired about web design principles, web programming methods, and software implementation, providing a holistic measure of students' accessibility knowledge.

Comparing Pre and Post Scores

Students in all conditions indicated a significant increase in their knowledge of accessibility-related programming techniques (α=0.05). Chapter 8 of this dissertation includes a qualitative analysis of students' project reports to understand how students apply their knowledge.

Table 6.5: Wilcoxon Signed Rank Test Results for the Awareness Questions Comparing Pre and Post Responses (Two-Tailed)

	No. Part.	**Pre Mdn (IQR)**	**Post Mdn (IQR)**	z	**p-value**
Lectures	64	1.08 (0.635)	1.21 (0.462)	-2.66	0.003*
Project	85	1 (0.769)	1.23 (0.423)	-5.56	$<$0.001*
Stakeholder	91	0.962 (0.5)	1.12 (0.423)	-5.19	$<$0.001*
Team Member	65	1.15 (0.423)	1.23 (0.538)	-3.11	$<$0.001*

Note. Asterisk (*) denotes significance at α=0.05, two-tailed.

Comparison Between Conditions

A Kruskal Wallis H test indicated that there were no significant differences among the knowledge score distributions of the conditions ($X^2(3)$=5.712,

p=0.126). This may suggest that all methods are similarly effective at increasing students' knowledge.

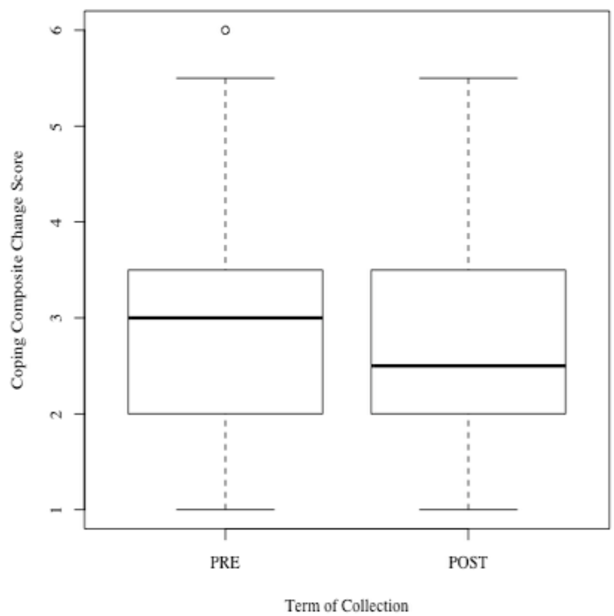
6.3.4 Attitudes towards Individuals with a Disability

The Interactions with Disabled Persons Scale (IDP) contained 20 ***attitude*** questions pertaining to six factors: *discomfort, uncertainty, fear, coping, vulnerability, and sympathy* [40, 45]. Lower scores on the IDP scale indicated *more ease* in interacting with individuals with a disability [40].

Comparing Pre and Post Scores

Wilcoxon Signed Rank tests were conducted for each condition and IDP measure. Only two IDP scale measures yielded significantly different results: *sympathy* and *coping*. Students in the *stakeholder* condition (n=*91*) obtained significantly more prosocial *sympathetic* attitudes (W=1760, Z=-1.72 p=0.043, two-tailed) at the post collection period (mdn=4.5, IQR=1) than the pre (mdn=4.75, IQR=0.875). All other conditions did not yield significant differences in the *sympathy* IDP questions (refer to Appendix G).

For the *coping* subscale, only students in the *lecture* condition showed significantly different responses at the post and pre collection period (W=733, Z=-1.83 p=0.033, two-tailed). Students in the *lecture* condition showed more prosocial *coping* results at the post collection period (*mdn*=2.5, *IQR*=1.5) than the pre (*mdn*=3, *IQR*=1.5).



Term	Min	Q1	Mdn	Q3	Max
Pre	1	2	3	3.5	6
Post	1	2	2.5	3.5	5.5

Figure 6.2: The distribution of pre and post coping scores for students in the *lectures* conditions were similar. The median was lower at the post interval, and there was one outlier in the pre interval, with a maximum score of 6.

It is possible that the *coping* subscale yielded significant results for the *lectures* condition due to an outlier. As shown in Figure 6.2, there was one respondent in the *lecture* condition who obtained a high score on the pre collection period (*score*=6), as calculated through the distributions' inter-quartile range (identified as: Q3+(1.5×IQR)). Indeed, when this data point was removed from analysis, the *coping* scores for the *lecture* condition were no longer significant: W=348, Z=-1.616 p=0.053, two-tailed. While we do not believe this data point should be removed, we note this to highlight the need for additional investigation into the *lecture* condition and *coping* measure in the future.

Comparing Between Conditions

No between-conditions testing was conducted for the IDP subscales as there were no competing conditions that yielded significant paired differences for the IDP subscale questions.

6.4 Discussion and Conclusion

The results of this study indicated that when students interacted with *stakeholders* or end users with a disability, they had the opportunity to obtain gains in four of the nine measures: *Voting scenario, sympathy, awareness, and knowledge.* *Projects* and *lectures* contributed to significant paired changes in three of the measures, while *team member* interactions only contributed to significant changes in *knowledge*.

Based on related work discussed in Chapter 2, we hypothesized that students with exposure to a *stakeholder* with a disability would yield higher ***knowledge, awareness,*** and ***attitude*** scores when compared to students in other conditions. Interacting with stakeholders for instance, had been found to increase students' empathy and awareness of accessibility. This hypothesis was also consistent with our prior work [78], where we found that students who had exposure to an individual with a disability gained more prosocial sympathetic attitudes, increased scores on the voting scenario questions, and increased knowledge of accessibility implementation techniques.

This study affirms our hypothesis and delineates the exposure category more concretely. It suggests that:

- Lectures were effective at increasing students' consideration of individuals with a disability when given a voting scenario question. Lectures also contributed to increased knowledge of accessibility implementation techniques and may be attributed to more prosocial coping attitudes towards accessibility.

- Projects on accessibility provided an additional benefit to the *lectures* by increasing students' first-hand awareness of accessible technologies. While the *lectures* included simulations and instructions for using a screen reader, for instance, it appeared that students did not seek additional experiences to further their *awareness* of accessible technologies.
- Stakeholder or end user interactions contributed to more prosocial sympathetic attitudes among students. These findings are consistent with prior instructors who have observed that although lectures contribute to higher ***knowledge*** of accessible implementation techniques, they do not impact students' attitudes towards individuals with a disability [99,100,108,109].

To further understand student's learning, this dissertation includes an analysis of students' project reports (Chapter 8) and longitudinal learning (Chapter 7 and 10).

Chapter 7

Longitudinal Evaluation of Efficacy with Questionnaires

7.1 Introduction

As outlined in Chapter 2, prior work on accessibility instruction in computing disciplines focused on a short-term evaluation of teaching efficacy. Long-term studies related to accessibility primarily focused on the broader evaluation of websites [47, 71, 76, 106], without a focus on computing education. In this chapter, we discuss an analysis of the long-term impact of the teaching conditions discussed in Chapter 3 and 6.

7.1.1 Research Question

We evaluated whether the short term changes observed in Chapter 6 were sustained by a subset of students 12-18 months after instruction on accessibility:

RQ 2. Does the Human-Computer Interaction course contribute to statistically significant changes in students' **long term** learning?

7.1.2 Hypothesis

It was hypothesized that the measures that yielded significant results in the short-term would continue to do so in the 12-18 month interval. That is, students would retain the lessons from the course as they would have future opportunities to reapply these insights in consequent course projects. As discussed in Chapter 6, the measures that yielded significant findings in the short-term were: ***knowledge, awareness, voting, coping, and sympathy***. Students in all conditions gained an increased knowledge of accessibility implementation techniques. Students in the *lectures* condition gained more prosocial coping scores. *Projects* contributed to an increased awareness of accessible technologies, and interactions with *stakeholders* contributed to more prosocial sympathetic attitudes.

7.2 Methods

Similarly to the pre and post collection of surveys, Information Technology (IT) and Software Engineering (SE) students were recruited through in-class announcements, course websites, emails, and flyers. All students were in the final year of their degree and had completed an HCI course with accessibility instruction 12-18 months prior. Questionnaire responses were collected throughout the academic year and each student was compensated with $20.

For each of the four conditions, we conducted a Wilcoxon Signed Rank test comparing the pre and senior questionnaire responses. By treating the pre response as a baseline measure, we were able to calculate whether the conditions were associated with any sustained changes in students' *voting scenario questions, IDP subscale, awareness,* and *accessibility knowledge.*

If a significant difference was observed between students' paired scores, we proceeded by conducting a comparison among the subset of conditions that had a significant difference between the "pre" vs. "senior" responses. A Mann-Whitney U Test was used to identify whether the scores associated with the conditions had significantly different results. Both the Mann-Whitney

U and Wilcoxon Signed Rank tests were conducted using the *Stats* package (version 3.6) of the R programming language [102].

7.3 Results

In an analysis of 65 students' pre and senior questionnaire responses, we found that students who had a ***project on accessibility*** or a ***team member with a disability*** sustained significant changes in their ***knowledge*** scores. No other conditions or measures, however, yielded significant changes at the 12-18 month interval. The 65 students represented the eligible population with an approximate 95% confidence interval and a 7.2% margin of error, based on the Cochran's formula for finite populations. This is a conservative estimate; it is likely that the 65 students represented a larger portion of the eligible participants (refer to Chapter 5).

Table 7.1 includes a summary of all significant results. Consequent sections will provide more detail into the results of each Wilcoxon Signed Rank test, including the corresponding IQR and test statistic values.

Table 7.1: Summary Wilcoxon Signed Rank Test *p-values* for Longitudinal Responses of Accessibility Knowledge, Awareness, and Attitudes

	Lectures	**Projects**	**Stakeholder**	**Team Member**
Voting	0.429	0.669	0.589	0.790
Sympathy	0.832	1	0.150	0.823
Vulnerability	0.151	0.566	0.137	0.315
Fear	0.297	0.576	0.436	0.274
Uncertainty	0.186	0.478	0.108	0.801
Coping	0.247	0.249	0.324	0.788
Discomfort	0.721	0.860	0.538	0.259
Awareness	0.620	0.554	0.421	0.975
Knowledge	0.208	0.002*	0.859	0.041*

Note. Asterisk (*) denotes significance at α=0.05, two-tailed.

7.3.1 Voting Scenario Questions

There were no significant differences between the pre and senior voting scenario responses of students in any of the conditions. As shown in Table 7.2, the distribution of the responses remained similar in the pre and senior interval.

Table 7.2: Wilcoxon Signed Rank Test Results for the Voting Scenario Question Comparing Pre and Senior Responses (Two-Tailed)

	No. Part.	**Pre Mdn (IQR)**	**Senior Mdn (IQR)**	***z***	**p-value**
Lectures	14	0 (0.5)	0.25 (0.5)	-0.179	0.429
Project	24	0.5 (0.625)	0.5 (0.5)	0.438	0.669
Stakeholder	11	0.5 (0.5)	0.5 (0.5)	0.224	0.589
Team Member	15	0.5 (0.5)	0 (0.5)	0.805	0.790

Note. Asterisk (*) denotes significance at α=0.05, two-tailed.

7.3.2 Awareness of Accessible Technologies

Similarly to the voting scenario questions, there were no significant differences in the awareness responses at the pre and senior interval. As shown in Table 7.3, students' scores were generally centered at a similar median during the pre and senior collection period.

Table 7.3: Wilcoxon Signed Rank Test Results for the Awareness Questions Comparing Pre and Senior Responses (Two-Tailed)

	No. Part.	**Pre Mdn (IQR)**	**Senior Mdn (IQR)**	z	**p-value**
Lectures	12	1.12 (0.188)	1.12 (0.25)	0.306	0.620
Project	23	1.12 (0.562)	1.12 (0.50)	0.136	0.554
Stakeholder	11	1.12 (0.375)	1.25 (0.312)	-0.20	0.421
Team Member	15	1.12 (0.438)	1.12 (0.375)	1.958	0.975

Note. Asterisk (*) denotes significance at α=0.05, two-tailed.

7.3.3 Knowledge of Accessible Technologies

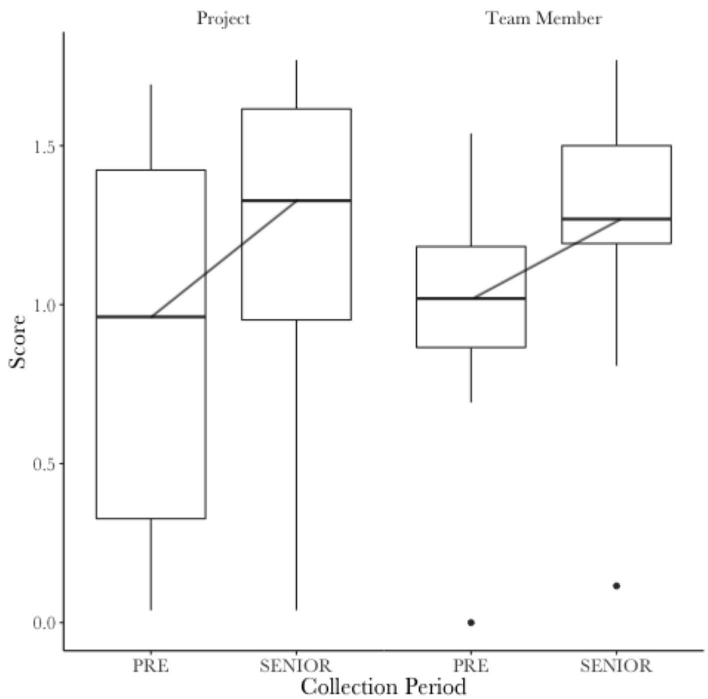
In an analysis of students' knowledge of accessibility, we found that students under the *project* (W= 36, Z= 3.66, p= 0.002) and *team member* (W= 19.5, Z= -1.737, p= 0.041) condition sustained significantly different knowledge scores 12-18 months after instruction (α= 0.05). All other conditions (*lectures* and *end user with a disability*) did not yield significant long-term changes (α= 0.05, two-tailed). Table 7.4 outlines all knowledge results for the Wilcoxon Signed Rank Tests. It was surprising that students in the *stakeholder and lectures* ***conditions*** did not sustain their short-term knowledge scores (refer to: Chapter 6).

Table 7.4: Wilcoxon Signed Rank Test Results for the Knowledge Questions Comparing Pre and Senior Responses (Two-Tailed)

	No. Part.	**Pre Mdn (IQR)**	**Senior Mdn (IQR)**	z	**p-value**
Lectures	14	0.962 (0.981)	1.29 (0.269)	-0.813	0.208
Project	24	1.33 (0.663)	0.962 (1.10)	-2.876	0.002*
Stakeholder	11	1.15 (0.442)	1.65 (0.731)	1.075	0.859
Team Member	14	1.02 (0.317)	1.27 (0.308)	-1.737	0.041*

Note. Asterisk (*) denotes significance at α=0.05, two-tailed.

Figure 7.1 delineates the distribution of pre and post knowledge scores: students who completed a *project on accessibility* had higher knowledge scores after instruction (Mdn= 1.33, IQR= 0.663) than before (Mdn= 0.962, IQR= 1.10). Students who had a *team member with a disability* also had higher knowledge scores after 12-18 months after instruction (Mdn= 1.27, IQR= 0.308) than before (Mdn= 1.02, IQR= 0.317).



Condition		Min	Q1	Mdn	Q3	Max
Project	Pre	0.038	0.327	0.962	1.423	1.692
	Senior	0.038	0.962	1.308	1.615	1.769
Team Member	Pre	0	0.865	1.019	1.183	1.538
	Senior	0.115	1.135	1.231	1.5	1.769

Figure 7.1: The students who were under the conditions of either a project on accessibility or a team member with a disability, sustained higher knowledge scores 12-18 months after instruction. The magnitude of the senior-pre difference was not significantly different, when comparing these two conditions.

Differences Between Conditions

Next, we conducted a Mann-Whitney U Test to assess whether there was a significant difference in the knowledge scores of students who completed *projects on accessibility* and who had a *team member with a disability*. We compared the change scores of the two samples by subtracting each students' senior score from their pre score. The results indicated that there were no significant differences in the distribution scores of students who completed *projects on accessibility* and who had a *team member with a disability* ($U=$ 185, $r=$ 0.269, $p=$ 0.955).

7.3.4 Attitudes Towards Individuals with a Disability

Wilcoxon Signed Rank tests were also completed for each of the Interactions with Disabled Persons (IDP) scale subfactors. When comparing the pre and post responses per condition, there were no significant differences. All IDP subfactor results are delineated in Table 7.6.

Table 7.6: Results for the Composite Pre and Senior Scores

Measure	Condition	Mdn Change	IQR Change	W-Statistic	Z-value	p-value	n
Sympathy	Lectures	-0.125	0.688	49	0.96	0.832	14
	Project	0	0.5	95.5	-	1	24
	End User	-0.25	0.875	42	-1.037	0.15	11
	Team Member	0	1	48.5	0.928	0.823	15
Vulnerability	Lectures	-0.5	1.375	42	-1.031	0.151	14
	Project	0	0.625	43	0.167	0.566	24
	End User	0	1	18	-1.095	0.137	11
	Team Member	-0.5	2	78	-0.481	0.315	15
Fear	Lectures	0.25	1.25	21	-0.534	0.297	14
	Project	0	1	79	0.192	0.576	24
	End User	0	1.5	35	-0.162	0.436	11
	Team Member	1	2.5	40.5	-0.599	0.274	15
Uncertainty	Lectures	0.5	1.667	31	-0.892	0.186	14
	Project	0	1.667	85.5	-0.056	0.478	24
	End User	-0.333	0.833	36.5	-1.238	0.108	11
	Team Member	0	1.333	57	0.847	0.801	15
Coping	Lectures	-0.5	1.25	54	-0.684	0.247	14
	Project	0	0.75	80.5	-0.679	0.249	24
	End User	0	2.25	25.5	-0.457	0.324	11
	Team Member	0	1.5	36.5	0.8	0.788	15
Discomfort	Lectures	0	0.4375	26	0.585	0.721	14
	Project	0	0.563	121	1.081	0.86	24
	End User	-0.5	1	34	0.094	0.538	11
	Team Member	0	0.875	32.5	-0.646	0.259	15

7.4 Discussion and Conclusion

In this chapter, we conducted a longer-term evaluation of students' survey responses to answer the research question, *'Does the Human-Computer Interaction course contribute to statistically significant changes in students' long-term learning?'*. We found that two out of the four teaching conditions were associated with an increase in students' knowledge of accessibility: completing a *project on accessibility* and having a *team member with a disability*. No other measures (*awareness, attitudes, voting scenario*) yielded sustained changes in the long-term.

Overall, we found that few of the significant short-term effects (refer to Chapter 6) were sustained in the long-term. It is possible that the lack of emphasis on accessibility within the curriculum impacted students' retention of accessibility-related information. Without reinforcement of the content within the curriculum for example, procedural nor semantic memory may have sustained in the long-term. Instead of making a conscious effort to retain this information, it is possible that students focused on developing skills emphasized in the curriculum. Prior work, for example, has indicated that students may deprioritize accessibility topics in computing due to such reasons [96]. In Chapter 10 of this dissertation, we discuss semi-structured interviews with senior-level students. These interviews provide insights into which factors dissuaded students from furthering their skills in accessibility.

Chapter 8

Qualitative Analysis of Project Reports

8.1 Introduction

As discussed in Chapter 2, researchers have used qualitative coding to assess computer accessibility ***knowledge*** [117, 118]. Qualitative coding was used in this dissertation to identify whether students applied their accessibility ***knowledge*** in project reports, and if so, how [1]. While we found in Chapter 6 that all students who were enrolled in the HCI course gained more first hand experience with accessibility implementation techniques, we were unsure if students applied this ***knowledge*** in their projects. The survey did not allow us to fully capture students' learning through a combination of closed and

[1] Findings discussed in this chapter were previously published at the ACM Special Interest Group in Computer Science Education (SIGCSE 2018) [78]

open-ended questions. As such, both the questionnaires and project reports were beneficial to understanding students learning and consequent behaviors.

8.1.1 Research Question

Similarly to Shinohara et al. [118] and Dong et al. [35], the project reports were analyzed through an inductive qualitative coding process. The two research questions addressed in this work were:

RQ 3.1 Do teams consider the needs of individuals with a disability at the onset of the project?

RQ 3.2 Do the four teaching conditions report significantly different tendencies in their consideration of individuals with a disability?

RQ 4 What sources of information do student teams use to justify their decisions related to accessibility?

8.1.2 Hypothesis

As discussed in Chapter 1, it was hypothesized that the majority of students *would not* consider accessibility within their projects. Teams that did consider accessibility, were hypothesized to choose target audiences with a visual or motor impairment [101].

In regards to the sources of information used, we hypothesized that students would primarily seek insights from individuals outside the team. Prior researchers reported automated accessibility evaluations, conference proceedings, and guidelines to be time-consuming to interpret [60, 66, 130, 144]. Automated accessibility evaluation tools were also found to result in false positives [49, 130]. It was possible that if students identified these shortcomings, they would be less willing to rely on secondary sources of information that summarized accessibility best practices.

8.2 Methods

All student-submitted project reports were collected from instructors at the conclusion of the HCI course, as approved by the RIT Institutional Review Board (Refer to Appendix B).

A total of 755 project reports (n_{words}=1,077,235) from 138 student teams ($n_{students}$=635) enrolled in the Human-Computer Interaction (HCI) course were qualitatively analyzed to identify patterns by which accessibility was considered. The 755 project reports were collected throughout seven semesters (spring 2016-2019) from seven unique professors.

To gather insights from the data, we developed inductive nodes that categorized major steps or themes in the data. These category nodes also contained subnodes to categorize the findings by the populations students considered in their work. The creation and assignment of these nodes will be discussed in the next subsections.

8.2.1 Node Creation

Ten nodes were used for qualitative coding, as described in Table 8.1. The nodes were created through an inductive process, whereby researchers independently identified themes in the documents and iteratively created appropriate tags. This section discusses the node revision history.

Node Revision History

Nine initial nodes were created by Miller [90] in spring 2016, through an analysis of one semester of data. These nodes included themes regarding software development processes, sources of information, and target audiences [90]. In summer 2017, an additional two semesters of data (spring 2016-2017) were coded. Once emergent themes in the documents were identified, the raters reconvened to compare notes.

Table 8.1: Qualitative Coding Nodes

Code	**Sample**
A person not on the team made a suggestion	"*Upon questioning it was found that users are unaware of features such as presentation view and popped window, but only use them on small screens or to make up for visual impairment*"
A person on the team made a suggestion	*"[The addition of] a settings button (color blind mode, disable/enable bottom menu, order homepage feeds, font size)"*
A person not on the team pointed out a concern	*"He described how joint pain and arthritis sometimes makes it difficult to use certain devices and expressed interest in the option for voice commands"*
A person on the team pointed out a concern	*"The environment in this room during the first time observing was not very conducive to those that may be hard of hearing as it was very loud in the room..."*
Accessibility considered but not adressed	*"Physical abilities: [user must be] physically and mentally capable of using Android applications and understand the information it provides"*
Original design of software included inherit accessibility components	*"Accessibility considerations we kept in mind while developing were users who would be using screen readers"*
Revising of software to consider accessibility	"*Added images to Events to signify extra features (handicap symbol, hands for interpreter)*"
Site customization allows for accessibility	*"Included on each page will be a slider that will change the font size of the screen content so that it is easier for people to see if default font size is too dificult to read"*
Students explicitly discuss accessibility guidelines	*"Have text and background [meet] WCAG 2AA constrast ratio thresholds"*
Target market includes a group requiring accessibility	*"When creating an app for locating healthy food on campus our group decided to take into account individuals who experience motor impairment"*

Similar themes were observed as Miller [90]; the reports were organized in a procedural manner, explaining the steps students took to arrive at their design rather than their motivations or inspirations. For this study, professors were expected to integrate accessibility modules into their courses but we were unable to dictate all the deliverables of the course. Furthermore, a targeted deliverable on accessibility could have biased future results, overriding the naturalistic nature of this part of the study.

A total of 10 nodes were created to describe the decisions teams made regarding accessibility. The nodes also described how teams came to a decision, such as *'A person not on the team pointed out a concern'* or *'Students explicitly discuss accessibility guidelines'*. All nodes were reviewed by three additional researchers to further ensure node clarity. Changes were made to the phasing of the nodes, but the overall themes persisted. Each node included multiple population sub-nodes: *Deaf or hard of hearing, learning or cognitive disability, mental health disability, mobility or dexterity disability, older adults, visual impairment* (refer to: Table 8.1).

8.2.2 Qualitative Coding Procedure

New design decisions were coded if accessibility was considered by students. When students considered accessibility, the goal was to identify what prompted the decision, who the target users were, and where in the project process the decision took place (refer to: Figure 8.3). One text excerpt could be assigned multiple nodes.

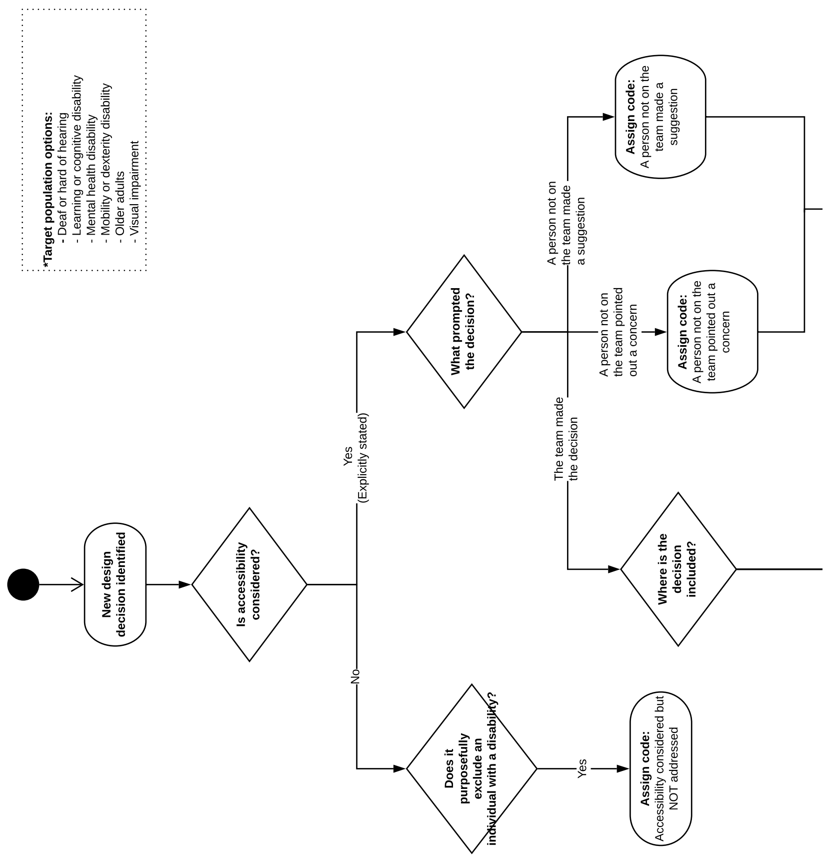


Figure 8.1: Qualitative Coding Process *(page 1 of 3)*

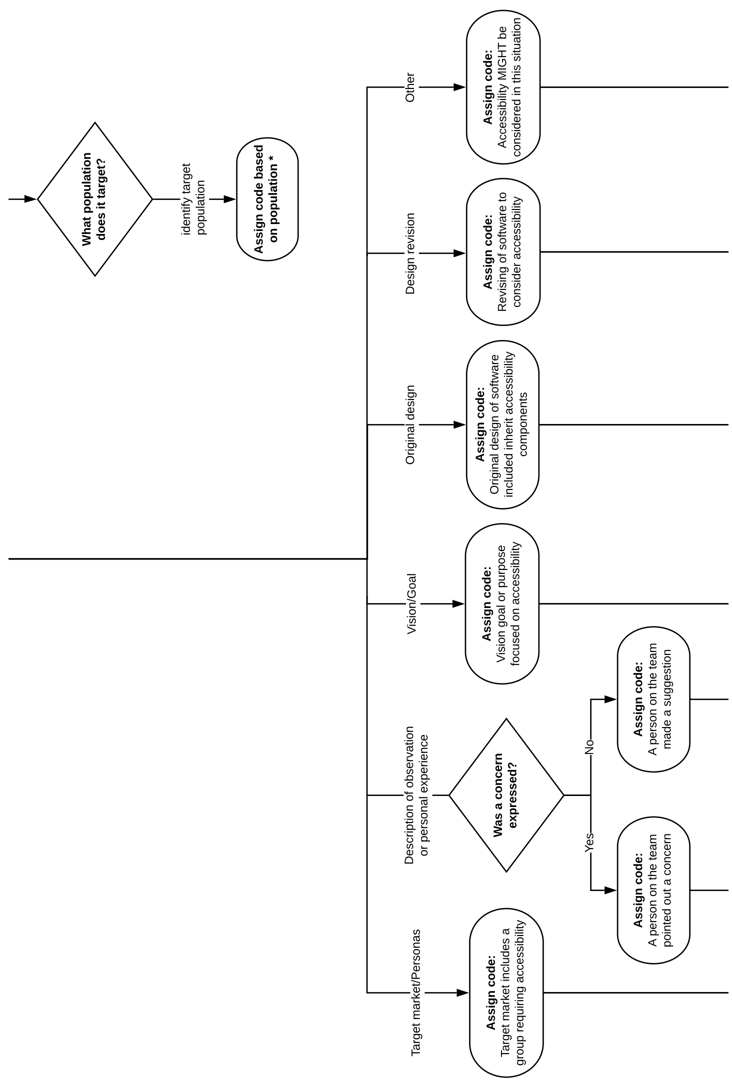


Figure 8.2: Qualitative Coding Process *(page 2 of 3)*

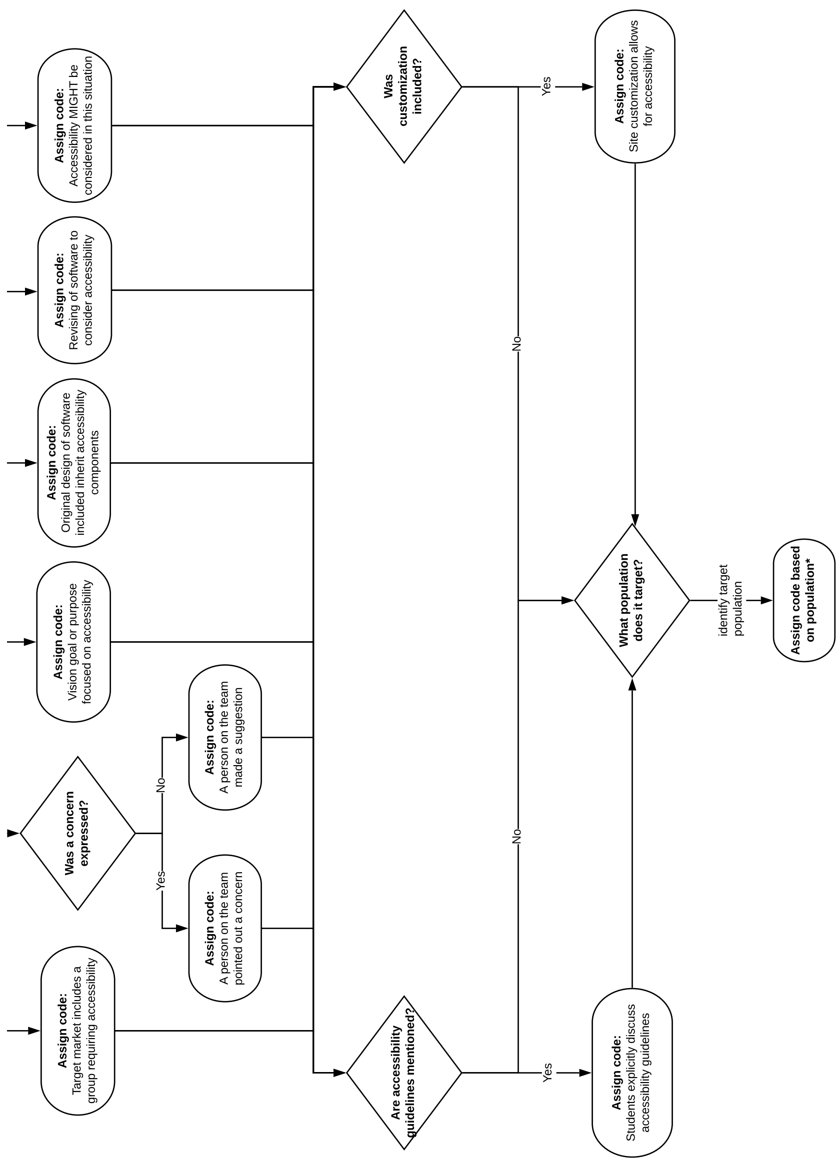


Figure 8.3: Qualitative Coding Process *(page 3 of 3)*

All raters independently coded the text excerpts and later reconvened to calculate their inter-rater reliability. When raters reconvened, they identified all coded text excerpts *without revealing the node assignment(s).* To reduce the likelihood of raters missing a code, each rater independently recoded the union of the text excerpts and revealed their complete node assignments. By removing the opportunity for raters to miss a text excerpt, we were able to use the Jacquard Index for our inter-rater reliability measure. Other measures, such as Krippendorff alpha and Cohen's kappa were incompatible with our data as they held the assumption that all nodes were equally likely to occur: some nodes such as, *'Accessibility considered but not addressed'* occurred less often than other nodes.

8.2.3 Inter-Rater Reliability

Since project report documents were collected from student teams during three years (from spring 2016 to 2019), the individual members of the annotation team changed during the multi-year project. To ensure consistency in annotation, a training procedure for annotators was created, including asking new annotators to label a common set of 20 project reports (which had previously been annotated by prior annotators on the project), to determine whether each individual annotator had sufficient inter-annotator agreement. The work of new annotators on these 20 documents was not actually used for the analysis in our study. Instead, these 20 documents were only used as a practice set of documents, to help new annotators learn about the annotation process. The activity of labeling these 20 documents, comparing their labels to the prior set of existing labels for these documents, and finally discussing their labels with another annotator who had already been working on the team, was used to help new annotators become acclimated to the project.

During training, differences in IRR scores were seen when annotators did not: consider the context of the text excerpts, know about different campus resources, or use descriptive nodes. For context of text excerpts, some annotators coded summaries of user responses as gathered by the team rather than sourced from a person outside the team. Another annotator did not know that the National Technical Institute for the Deaf (NTID) was predominately for deaf and hard of hearing students. Lastly, the final annotator used the code *'Original design included inherit accessibility components'* for instances where other codes were more descriptive, such as relating to end users or site customizations. These insights were used to improve training documentation, such as noting that the format of the report should be reviewed before assigning labels to text excerpts.

We calculated the IRR scores for the 20 pre-coded reports that were used to train four researchers: 80%, 74.7%, 67.5%, and 77.9%. After this training, the raters began qualitative coding on uncoded reports. The labels for the new data were used to calculate the final inter-rater reliability. The reader should consider these initial lower IRR scores as the 'starting point' for a new annotator who joined the team and who had merely read the annotation guide, without receiving any feedback. The annotators work on these training documents was discarded at the conclusion of the training procedure.

Traditional measures of inter-rater agreement often assume that agreement is being compared on a per-word or per-sentence basis throughout a text, but this may not be suitable for annotation projects in which a majority of the text does not receive a node label. For projects such as this, an alternative inter-annotator agreement statistic referred to as the cumulative Jacquard Index is used instead. This metric only considers the set of texts that have received any label by any annotator, and the agreement among annotators is calculated upon this set.

To calculate the Jacquard Index for our project, we first asked annotators to label segments of text, then across all annotators for a document, a union of all texts that had been labeled was collected. All annotators were asked to consider this union of text segments and to assign a label (or determine that they did not believe any label should be added to a specific segment of text). Finally, the Jacquard Index score was calculated.

In total, a set of six annotators worked on the project during the years 2016 to 2019. In total, they annotated 755 documents from student teams in the HCI course. Each individual project report document was independently annotated by at least one human annotator, and some documents were independently labeled by as many as two human annotators.

Across all 755 project reports (n_{teams}=138) from spring 2016 to spring 2019 semesters, the cumulative Jacquard Index was 93.6%, where a score of 100% indicated perfect agreement. A total of 89 out of 138 student teams (64.5%) mentioned accessibility in their project reports, generating 472 codes.

There were only 14 disagreements between the researchers who conducted qualitative coding. A sample disagreement was for the excerpt *'The vending machine would recognize a user with visual disability when they approach the vending machine and say 'Activate Voice Commands'.* This was initially assigned *'Original design included inherit accessibility components'* by one of the raters, but upon discussion, the raters agreed that *'Customization allows for accessibility'* was more descriptive. In a similar way, for all cases of disagreement among annotators, a consensus meeting was held, in which two annotators discussed a code, to determine how it should be labeled in the final annotation dataset.

8.3 Findings

An overview of the team conditions and mentions of accessibility are outlined in Table 8.2. Team's mention of accessibility did not differ by the type of teaching condition they were exposed to ($X^2(3,\ n{=}138){=}3.096,\ p{=}0.378$). A teams' mention of accessibility could be positive or negative, e.g., students could indicate that they explicitly did not want to make their product accessible. Such mentions were tracked under the philosophy that the students indicated a minimum level of awareness or consideration of accessibility. While all prior chapters included an analysis of students learning in each of the four conditions, this chapter considers all of the student teams in the HCI course, regardless of which of the four conditions they experienced.

Table 8.2: Number of teams per condition who mentioned accessibility in project reports

Condition	**No mentions of accessibility**	**Mentioned accessibility**
Lectures	19	33
Project	15	23
End user	11	16
Team member	4	17

8.3.1 Choosing a User Group with a Disability

Student teams incorporated accessibility within their projects in one of two ways: creating a product to address a need for a wide audience (e.g., communication, finance, etc.) or directly choosing individuals with a disability as a target user group and prioritizing their needs. Of the 138 teams, 89 teams (64.5%) mentioned accessibility in their project reports: 15 teams did not choose a user group with a disability (instead they designed for a specific *need* and made it broadly available), 68 teams chose to design for a user group with a disability, and 6 teams explicitly *excluded* individuals with a disability. Teams that chose to design for end users with a disability reported considering accessibility earlier in the process. This section discusses the target user groups that the 68 teams considered.

The proportion of teams that mentioned accessibility and chose a target audience with a disability can be seen in Table 8.3. There were no significant differences between the teaching conditions teams were exposed to and their selection of a target audience with a disability (Fisher's Exact Test, p=0.430, two-sided).

Table 8.3: Number of teams who mentioned accessibility and chose a target audience with a disability

Condition	**Chose a target audience with disability**	**Didn't choose a target audience with disability**
Lectures	25	8
Project	15	8
End user	14	2
Team member	14	3

Among the 68 teams that chose a target audience with a disability, 30 teams chose two or more target audiences with a disability. Overall, the most commonly considered end users were individuals with a mobility impairment, who were deaf or hard of hearing, and who had a visual impairment. Learning or cognitive impairments, in addition to, mental health disabilities were considered less often. The presence of the National Technical Institute for the Deaf may have motivated students to consider individuals who were deaf or hard of hearing. As one team explained,

> *"[We] mainly focused on deaf and hard of hearing students at Rochester Institute of Technology who have difficult times [when] ordering food when the server has no knowledge of American Sign Language"*

When comparing teams that designed for a wide audience versus those who designed for a specific group of people with a disability, a major difference was observed in their consideration of features that went beyond a person's capabilities. One team considered their users' communication with family members:

> *"Once the most essential requirements were achieved, the most desirable requirements were looked into, such as the addition of family profiles with custom reminders, companion health products*

> *like blood sugar readers, and customization for accessibility such as changeable fonts and colors"*

Similarly, another team who prioritized the needs of individuals who were deaf or hard of hearing choose input modalities that best fit their users' preferences. This decision went beyond a simple solution that avoided audio output, to providing greater flexibility for the user. The teams' decisions showcased their understanding of the individual preferences which could vary among people who are deaf or hard of hearing:

> *"To meet this goal we designed a chat system that has the option to screen-share and will have the option of video relay. Initially we were thinking that just chat would be sufficient but after our discussions we determined that having an option for video relay would be the best way to support NTID students. Video relay is essentially an interpreter that can be used over video, providing the comfort of being able to use ASL in a conversation over this chat program."*

These findings suggested that students benefited from committing to a target audience with an accessibility use case. It increased students' consideration of user needs beyond accessible functionality and allowed them to customize the technology for different contexts of use. It is possible that choosing a target audience with a disability allowed teams more time to address topics related to social participation, individual preferences, and user privacy.

Mentioning Accessibility but not Addressing it

During the analysis of the project reports, we also encountered cases in which teams mentioned an accessibility issue, but they did not actually do the work of addressing this challenge in their design or implemented system. One team identified technical difficulties that could not be resolved before the completion of the course:

> *"Decided against keyboard shortcuts. Not very useful and would conflict with OS keyboard shortcuts."*

An additional team was unable to implement voice functionality within the device, possibly due to technical challenges:

> *"We also had plans to design for the completely blind by implementing voice commands and displaying information in a screen-reader friendly fashion."*

Among the 138 student teams, we found that six teams specifically discussed in their project reports that they decided to exclude people with disabilities from the use of their technology. Three teams excluded either individuals with motor, visual, or learning impairments. The remaining two teams excluded all individuals with a disability. No reasoning was provided for exclusion:

> *"[users must be] physically and mentally capable of using the Android application and understanding the information that it provides."*

Another team who excluded individuals with a disability did not provide accessible features, instead requiring users to adapt to the website:

> *"Does not account for disabilities. User must accommodate for their disabilities prior to using the site."*

Ensuring that students can advocate for the end user is an important component to advancing mainstream accessible technologies [127].

8.3.2 Sources of Information Used by Teams

Student teams reported using a variety of primary and secondary sources to inform the design of their projects. We refer to primary sources as original sources of information - gathered directly through a user's account in interviews, personal journals, etc. Secondary sources are summarized information gathered by an external party, such as accessibility guidelines or user test reports. A total of 35 out of 138 teams reported using primary sources of information to justify their decisions. Consulting with individuals outside the team was the most common, with 31 teams noting such insights. Only six teams mentioned referencing accessibility guidelines.

Insights From Individuals Outside The Team

The 35 teams that reported applying insights gained from individuals outside the team used interview, usability studies, and intercept methods. Interacting with individuals with a disability allowed students to identify unmet needs, users' mental models, and workarounds. For instance, one team interviewed Deaf and hard of hearing students to understand their needs:

> *"[The participant] talked about how he wished that NTID had more tutors. There was only one tutor running by the hour. He said that having one more tutor would help answer students' questions much faster."*

Based on these insights, the team designed an online tutoring service with customized communication features for American Sign Language and spoken or written English.

Four of the 35 teams interviewed individuals who *worked* with individuals with disabilities. Proxy users included caretakers, doctors, interpreters, and therapists, who provided context of the broader needs of individuals with and without disabilities. One team created a website that allowed access to health information. Although the product was initially designed for individuals with a disability, the team shifted their attention to other family members:

> *"Some loved ones feel powerless and uninformed about their associated patients' health and wellbeing. How can we provide loved ones with helpful and appropriate information about a patient's health?"*

The teams who interacted with proxy users focused on an individuals' lack of ability. This finding is consistent with prior work which highlights how proxy users may contribute to a limited understanding of disability [113, 120].

Insights From Accessibility Guidelines

Six teams explicitly discussed the use of accessibility guidelines. Teams primarily referenced color guidelines for contrast ratios and tones, to support individuals with color blindness and visual impairments:

> *"Text and background need to meet WCAG 2AA contrast ratio thresholds."*

8.4 Discussion and Conclusion

A review of the inter-rater reliability of the dataset suggested that the nodes and processes were reliable among different raters and document topics. Over time, we refined the training documentation to support future study replication. Our high inter-rater reliability scores were challenging to obtain, but were achieved through a well documented process with consistent evaluation. The methodical decision-making process for assigning new nodes further ensured a systematic assignment of qualitative nodes.

Through a coding of the project reports, we were able to gather contexts by which students considered accessibility. While this analysis provided a description of students' learning, it also arose a new set of questions regarding students' motivation. The results of the project reports were polarized; 89 out of 138 (64.5%) of teams mentioned accessibility and less than half of those teams (35/89, 39.3%) cited information sources to justify their decisions (end users, guidelines, etc.). This section discusses the results in context of the research questions.

RQ 3.1. Do teams consider the needs of individuals with a disability at the onset of the project?

Of the 138 student teams, only 68 teams chose to consider the needs of individuals with a disability at the onset of their project. **While modern definitions of disability consider factors beyond a persons' abilities (social stigmas, environment, etc.) [148] - our findings indicate that students are not likely to consider these factors when they do not commit a target user group with a disability.** Teams that simply created mainstream accessible technologies, without an explicit consideration of individuals with a disability, excluded factors that contributed to modern definitions of disability.

In regards to the selection of target audiences, the results were consistent with our hypothesis. The majority of teams did not consider individuals with a disability nor mention accessibility in their project reports. This is consistent with research indicating how accessibility and usability topics are often considered an afterthought [96, 117]. Teams who did consider individuals with a disability, primarily considered individuals with low vision, motor impairments, and who were deaf or hard of hearing. This suggests that professors may need to provide additional emphasis on topics related to cognitive impairments and mental illness.

RQ 3.2. Do the four teaching conditions report significantly different tendencies in the consideration of individuals with a disability?

When testing the frequencies by which teams considered individuals with a disability at the onset of the project, we found that there was no significant differences between the conditions (p=0.430, two-sided). Overall, few teams applied accessibility in their projects (n=89/138, 64.5%) and fewer teams considered individuals with a disability as part of their target user group (n=68). Chapter 9 discusses interviews with senior level students to further understand why students did not apply accessibility.

RQ 4 What sources of information do student teams use to justify decisions related to accessibility?

A total of 35 out of 138 teams cited sources of information (end users, guidelines, etc.) to justify their decisions. Consulting with people outside the team was the most common. Only six teams referenced accessibility guidelines. While prior research has indicated several limitations of guidelines [60, 66, 144], the project reports did not reveal whether this was caused by motivation or resources available.

The reason why a qualitative analysis had been conducted among students' written work was that it was a way to understand their thinking and decision-making about accessibility without explicitly engaging in a discussion of these topics among students in the course, since engaging in such a discussion would risk influencing the results of the longitudinal survey of these students two years later. The goal was to understand as much as possible about the student's thinking about accessibility without interfering with the natural execution of their HCI course. However, this analysis has opened several logical questions which could not be answered through analysis of these written project reports alone.

Chapter 9

Senior-Level Student Interviews

9.1 Introduction

In Chapter 6 we found that in the ***short-term***, all teaching conditions contributed to a statistically significant increase in students' ***knowledge***. Although all conditions were associated with an increase in students knowledge of accessibility implementation techniques, only 89 out of 138 teams (64.5%) reported applying that knowledge in project reports (refer to: Chapter 8). Upon review of students' ***longer-term*** knowledge, we found that only a subset of the conditions (*project* and *team member*) contributed to sustained ***knowledge*** gains (refer to: Chapter 7). To further understand students' learning and motivations, we conducted interviews with senior-level students. All students had completed the HCI course and been exposed to varying teaching conditions.

9.1.1 Research Question

Sixteen senior-level students were interviewed to understand which educational experiences influenced their learning of accessibility:

RQ 5. In interviews about their educational experience during their university career, what factors do students believe have influenced their accessibility knowledge?

9.1.2 Hypothesis

From a practical standpoint, students have been reported to face challenges in participant recruitment [80], accessibility testing [62], and requirements elicitation [77, 117]. Social and extrinsic factors have also been highlighted as influencing students' and professionals' motivation to learn new computing topics. In a thematic analysis of 17 semi-structured interviews, McCarthy et al, found that computing students were motivated to further their knowledge of computing topics if there was a strong peer or social influence: *wanting to belong* to a group who was perceived to have specific skills, *fear of appearing ignorant on a topic*, or the desire to learn *hip new concepts* [86]. Similar findings were also observed by Jenkins [55], whereby students were motivated to learn programming topics if the content was associated with their career goals. While prior work did not focus on students' *motivation to learn about accessibility*, we hypothesized that similar social or extrinsic influences would be mentioned by students.

Social and extrinsic factors have also been found to influence computing professionals: an *inclusive company culture* and *supportive top-level management* increased computing professionals' commitment to creating accessible technologies [13, 46]. In contrast to industry efforts for a more inclusive culture [146], many computing degree programs have been reported to not be inclusive of underrepresented groups, including women and minorities [5, 145]. An interview study allowed us to understand how students' shape their knowledge of accessibility, and whether they identify any external factors as motivating or dissuading them from learning more about accessibility.

9.2 Methodology

Sixteen 45-minute semi-structured interviews were conducted with senior-level students in a conference room from October 2018 to February

2019. A total of 11 questions were asked to participants pertaining to their background knowledge, exposure to diverse users, barriers in computing education, and their overall education at Rochester Institute of Technology (RIT). All interviews were audio recorded for transcription.

9.2.1 Participant Recruitment

Students were recruited through emails and in-class announcements. The inclusion criteria included: enrollment in a Software Engineering or Information Technology undergraduate degree program, in the final year of their degree, completion of a co-op in their field, and completion an HCI course with accessibility instruction. A total of 16 students participated in the interviews and they were compensated with $20 cash. Three out of 16 participants were female, consistent with the gender ratio of the university [92]. The majority of participants had been exposed to the *lectures* condition (*n=9*), followed by *project* (*n=3*), *team member* (*n=3*), and *stakeholder/end user* condition (*n=1*). All interviews were conducted after the senior-level questionnaires were administered (refer to: Chapter 7).

9.2.2 Interview Questions

The semi-structured interview questions were organized into four sections: *background, exposure to diverse users, barriers in computing education, and accessibility education at RIT*.

Background

Three background questions inquired on students' experience with usability. The first question was, *'Would you describe yourself as a beginner, experienced, or very experienced in addressing usability issues in software?, Why?'*. Omitting the term *'accessibility'* allowed the researcher to understand students' frame of reference and to adapt probing questions accordingly. As discussed in Chapter 2, accessibility is often interpreted as a usability consideration that bolsters experiences for all users *or* a compliance-focused specialization that benefits few users. If students perceived accessibility as a synonym of usability, it may have been difficult for them to express considerations that only applied to individuals with a disability.

Exposure to Diverse Users

Three additional questions focused on participants' exposure to diverse end users. One question asked, *'When was the first time that you considered creating software for individuals with different abilities from your own?'*. This question purposely omitted the term *'disability'* to provide students an opportunity to discuss diverse users who could broadly benefit from accessibility considerations. For example, students could reflect on instances when they created software for children and referenced accessibility guidelines regarding literacy levels.

Challenges in Computing Education

Three questions focused on RIT courses and the challenges faced by students. Probing questions focused on students' consideration of accessibility, their motivations, and the course descriptions. One important question was, *'Is there anything the professor could have done to help you implement accessibility?'*. The goal of this question section was to understand the challenges students faced, and to gather a list of recommendations for improving accessibility instruction.

Accessibility Education at Rochester Institute of Technology

The last set of questions focused on students' awareness of accessible technologies and their perceived preparedness in creating accessible technologies. The first question asked, *'Can you recall a time when you saw someone using an accessibility feature or technology that you were not exposed to?'*. The purpose of the question was to prompt a discussion of students' exposure to accessible technologies. It was possible for instance, that students would identify the use of captionists at RIT.

Students were also asked about the sources of information they would need to feel prepared to create accessible technologies. These questions helped reveal students' motivations and indicated how difficult they perceived accessibility topics to be. Finally, the last question asked, *'How has RIT's focus on accessible education, such as interpreters and flipped classrooms, changed the way you think about computing?'*. This leading question was added to the end of the interview to provide students one final opportunity to identify areas of their education that may have implicitly impacted their knowledge of accessibility.

9.2.3 Qualitative Analysis Procedures

We used the Grounded Theory method of Corbin and Strauss [26], conducting interview sessions in conjunction to analysis. Two stages of analysis were conducted beginning with open and axial coding, followed by selective coding. All stages of analysis were conducted by three researchers.

During open and axial coding, researchers independently reviewed 2-3 batches of transcribed interviews. They assigned in vivo categorical labels to concepts present in the transcripts and reconvened to compare their individual labels and field notes. A constant comparison method was used to establish the relationships between the labeled concepts, thereby commencing axial coding. In axial coding, all relationships were established, including contexts, co-occuring labels, and causes. A literature review was also conducted during axial coding to review the theoretical support, or contradiction, of the findings.

During the last stage of coding, selective coding, the researchers divided the interviews among themselves and reviewed them to ensure accuracy in the final axial codes. After this, one researcher reviewed all of the interviews, annotating which participants were exposed to what condition and whether or not they expressed the high-level concepts gathered during the analysis. Multiple efforts were made to maintain unbiased results:

- In vivo codes were used to avoid labeling texts based on preconceived ideas or assumptions. In vivo codes required that category labels were generated as closely as possible to the participant's language.
- Each researcher on the team had a diverse background with distinct domain knowledge. The researchers had completed different degrees (psychology, design, and computer engineering) at varying universities (Rochester Institute of Technology, Shanghai Normal University, and University of California Santa Cruz). This ensured that the data was not analyzed based on homogeneous ideas.
- All researchers independently developed their own labels and field notes. Furthermore, all discussions, memos, and interpretations were carefully documented throughout the analysis to assist in the constant comparison of participants and their developed categories.

9.3 Qualitative Findings

In interviews, students identified three extrinsic factors that dissuaded them from considering accessibility in their work: *a learn-it-on-your-own approach, a lack of accessibility content in the curriculum, and a perception that accessibility was not important to their careers.* Only two out of 16 students were self-motivated to learn more about accessibility.

9.3.1 Learn-it-on-Your-Own Approach

Students described an implicit expectation to learn new content on their own, and that this approach made them hesitant to learn new content related to accessibility. They described professors and managers as *'hands-off'* and whose *'primary role [was] to give requirements'*. P3 explained:

> *I think kind of the culture is that professors are very hands-off for the most part. That is how I've always seen it. Even in some experiences that I've had, it's been like, 'well you can look for it on your own, I don't have the time, I don't have to tell you the solution'. Like the solution may be somewhere that you just have not looked.*

Instead of approaching professors to learn new content, students relied on online resources to meet an assignments' requirements. P11 expressed discomfort and embarrassment in asking professors for help:

> *I try to learn it on my own first... I think most of the time, I am embarrassed that I don't know it and so I try to get as much information as I can before asking professors. But whereas, with my colleagues, like my student peers, I would probably just ask them...I would Google it, and Google it, and Google it... and then maybe ask a close peer and then a professor.*

Similar findings were also observed in workplace environments, where students relied on online resources to complete their tasks. When P16 was asked how they acquired the skills to complete on-the-job tasks, they mentioned the use of online resources due to their manager's unavailability:

> *Google, really. Our mentor wasn't available to help us all that much, but they were like, 'you have to have this done by a certain date' so, we spent a lot of time on Google.*

In addition to avoiding professors and managers, students also expressed hesitance in interacting with individuals with a disability. P15 shared that they were interested in the communication between students who were hearing and hard of hearing, but that doing a project on the topic would be difficult because of the unknown etiquette:

> *Knowing, I don't really know how to label how deaf is that person. What do I talk to them about? How would I communicate with them?... So, kind of on that level. If I need to take out my phone to write a message to them, or if I need to mouth words, if they can read lips really well, then sometimes things like that we can work out... I guess I would want to know how comfortable the deaf or hard of hearing person would feel in that case.*

In addition to a *learn-it-on-your-own approach*, students were dissuaded by a lack of accessibility topics in educational and workplace settings, as will be discussed in the next section.

9.3.2 Not Required to Consider Accessibility

Students explained that they only considered accessibility when it was required of them. They noted that person-centric topics, such as accessibility and usability, were not prevalent in the curriculum, nor was accessibility explicitly mentioned in any software development process (e.g., agile, waterfall). They observed courses primarily focusing on functional requirements and satisfying the needs of stakeholders rather than the needs of end users. This lead to a decreased motivation to address accessibility needs:

> *Well, I'm going to do the requirements for the class project and I'm not going to try to go super above and beyond. Like, it's not going to matter. Just as long as you get the A, a 96 or a 99, it doesn't matter either way.*

Participants' focus for meeting functional requirements continued into workplace environments. Students did not create accessible technologies unless it was explicitly required of them. In total, only 7 out of 16 students considered accessibility during their internships, all of which were required to do so. When P14 was asked what motivated them to consider accessibility in their internship, they replied, *'it was my job'*, and that they had to follow their manager's orders. P16 also explained how they created an accessible website during their internship because they had to meet U.S. 508 compliance [131]:

> *We had to create a website with 508 compliance in mind which is like dealing with screen reader technology.*

When accessibility was not required, students expressed that they tended to think about users similar to themselves. P1 explained that accessibility was not a topic that they commonly thought about:

> *Probably because we just don't really think of [accessibility]. When we are going to create those applications, it's easy to have tunnel vision with what you know. Like, I don't have disabilities, so I don't think about it. I feel like that is the main issue, that a lot of people don't think about the situation of others.*

P3 self-disclosed as having a disability and also shared a similar view:

> *Well I know because I am color blind, like red green deficient, I do look out for those things only because it helps me also.*

Without direct requirements, students were not in the habit of considering the usability or accessibility of their software. We note that the curriculums within this study follow computing guidelines and that the Software Engineering curriculum is also ABET accredited [2]. In the next section, we elaborate on the workplace and educational contexts that contributed to students perceiving accessibility as non-essential to their careers.

9.3.3 Not Seeing Accessibility as Important for a Computing Profession

The last major factor that dissuaded 14 out of the 16 participants from considering accessibility in their work was that they did not perceive the topic as being essential for their career. In particular, twelve out of 16 participants expressed that accessibility was necessary in select *front-end* development roles or domains, e.g. healthcare, government, or access services:

> *Probably not, only because there is a lot of people who have a strong focus on backend implementation. While there are minor implementations of accessibility within the backend, it tends to be a front-end focused discipline. At least that is my view.*

Participants also indicated that they did not think that accessibility would be a priority in startup companies or industry sectors where they anticipated few users with a disability. When P3 was asked whether they foresaw themselves applying accessibility in their future career, they explained that they expected to only if it was specifically asked for:

> *I would say yes, but only when it is specifically asked for or necessary. In terms of cost of a project, when it comes to time and how it relates to money, the core requirements are usually going to be to get the project done first, and secondary would always be the accessibility to it. If it was designed specifically for a type of user, then it would be designed to be dedicated for that specific user.*

Students who were required to incorporate accessibility in their internships also shared similar statements. Seven out of 16 students were required to apply accessibility during their internship, and **only one of these students stated that accessibility skills would be needed by all computing professionals.** The remaining students were dissuaded by the lack of importance their company and co-workers placed in accessibility skills. P5 described that their co-workers did not know how to use screen readers:

> *I had to Google it because all the other coworkers on my team were like, 'I don't know, we just Google it every time we need to do it too'.*

Participants also mentioned a lack of established processes or guidance for applying accessibility:

> *First was learning about compliance. Everyone kept throwing this [word] around, but they didn't really tell us what it was about, so [another intern and I] read up on 508 [compliance] and some of the other laws surrounding that too.*

Overall, students observed that accessibility was not necessary to complete many on-the-job tasks and neither their co-workers nor their companies appeared to place a high value in developing processes for ensuring accessibility. Instead, the process of learning or implementing accessibility was an isolating process.

9.3.4 Motivations for Computer Accessibility: Exception Cases

Two out of 16 participants *(P8, P9)*, indicated that they were motivated to continue their learning of accessibility after the HCI course. The two students were motivated by their meaningful interactions with individuals with a disability and the mentorship they received from managers or professors.

Both participants had meaningful interactions with individuals with a disability. P8 interacted with Deaf individuals and observed that some had limited fluency in English which contributed to fewer professional experiences. P8 was inspired to design an application that could help Deaf individuals improve their English:

> *Seeing that a lot of Deaf people have potential but are limited by their English. Because of that, they are not given a shot, even though it has nothing to do with their English. This app is a way to help them to move up somehow.*

Similarly, P9 grew up around individuals with disabilities and was driven to create accessible technologies:

> *I grew up in an environment that had people from many different backgrounds and disabilities. I wasn't told [to do it] but thinking about them now, makes me want to make sure that I can account for them.*

Both students were also motivated to continue their learning of accessibility due to positive mentorship experiences. P8 completed a Research Experiences for Undergraduates (REU) summer research program sponsored by the U.S. National Science Foundation (NSF) where accessibility was required. The program matched them with faculty research mentor(s) who guided them through the process. At the conclusion of the program, P8 was provided additional support from the college to continue implementing the project, including support for pairing with other students. This additional support from the university reinforced the importance of accessibility within the computing domain.

P9 was required to complete an independent-study course when they transferred into the major. They were matched with a professor who had experience in accessibility and who highlighted the role of accessibility within software development. This experience made them more interested in the experiences of individuals with low vision:

> *I have actually tracked a few academic papers but those primarily talk about interactive braille pad, which is still not perfected... I have kept an eye on it though. I hope that it gets produced.*

These experiences highlight the role that an educational culture can have in shaping students' self-motivation to learn about accessibility. Mentorship experiences for example, not only counter a *learn-it-on-your-own approach* but also expose students to professionals who apply accessibility in their work.

9.3.5 Recommendations for Computing Education

The last portion of the interview regarded students' recommendations for how courses could promote accessibility. We directly asked them, *'Is there anything the professor could have done to help you create accessible technologies for individuals with a disability?'*. This question was posed at the end of the interview to allow students to reflect on the information resources, educational experiences, and training that was previously discussed.

We gathered 21 recommendations from students that could be categorized into three areas: ***Topics for learning accessibility***, ***Resources***, ***Course structure***. The 21 recommendations are itemized below:

- ***Topics for learning accessibility:*** Gathering software requirements related to accessibility, disability etiquette, incorporating accessibility in the software development cycle, Deaf culture, accessible technologies or devices, authoring website content, testing software for accessibility, and communication preferences of different individuals with a disability

- ***Resources:*** Examples of accessible technologies, APIs or programming frameworks with accessible features, books or websites on accessibility, list of professors that specialize in accessibility, guest speakers with a disability, accessibility guidelines and regulations, automated software accessibility evaluation tools, online courses or tutorials, list of organizations that support individuals with a disability.

- ***Course structure:*** Add accessibility requirements within existing course work and classes, add a required accessibility course for my degree, create an elective course that counts towards my major, and ability to take courses outside the college that will count towards my major.

To prioritize these recommendations, we conducted a survey with a broader population of computing students. This survey is discussed in Chapter 10.

9.4 Discussion and Conclusion

Through interviews with senior-level students, we sought to answer the research question, *In interviews about their educational experience during* *their university career, what factors do students believe influenced their accessibility knowledge?* We hypothesized that students would continue to apply accessibility after the HCI course and that their success in doing so would be dependent on the challenges they faced in projects.

The semi-structured interviews and Grounded Theory approach allowed us to discover that **there were no specific project factors that detracted students from implementing accessibility**. Instead, students did not tend to think about accessibility from the onset, even if they had been exposed to varying teaching conditions 12-18 months prior. The only **temporary** change to this phenomenon were requirements on the topic.

Social and extrinsic factors influenced students' motivation to continue their learning of accessibility. Students expressed discomfort in approaching professors and managers with questions, indicating an implicit expectation to *learn content on their own.* Furthermore, they expressed discomfort in communicating with individuals with a disability. Computing students experiencing discomfort when interacting with individuals with a disability has also been found in prior work [77, 117].

Teaching strategies that countered a *learn-it-on-your-own approach*, such as with one-on-one instruction and meaningful interactions with individuals with a disability, appeared to motivate students to learn more about accessibility. It is possible that these methods contributed to social and extrinsic motivators, such as the desire to meet authoritative figures' expectations which has been found to be influential in industry settings [13, 46].

In addition to the social detractors in a *learn-it-on-your-own approach*, participants expressed that they did not see accessibility as an essential skill in preparing them for their careers. They indicated that accessibility was a specialization that would be used in select industry sectors. This aligned with students' experiences in co-ops: coworkers and companies appeared to place a low value in memorizing accessibility-related skills and there were minimal processes in place to ensure accessibility was implemented. This also aligned with students' educational experiences where accessibility was not a main focus of the curriculum. In the next chapter, we discuss a survey of senior-level students which prioritizes the recommendations provided during interviews.

Chapter 10

Student Prioritization of Educational Methods

10.1 Introduction

In Chapter 9, we found that students did not consider accessibility in their work, and that this phenomenon was influenced by extrinsic factors, such as *not being required to consider accessibility* in the curriculum nor in work experiences. These results made us wonder which teaching methods could best address the concerns expressed by students. To build on prior work which had identified possible interventions via surveying professors [100, 119], we conducted a survey of students to evaluate a list of initiatives that in retrospect, could have better prepared students to consider accessibility.

While the students in our interviews in Chapter 9 had identified some possible educational interventions that may have benefitted them, in a small interview study, it was not possible to prioritize these recommendations according to students' level of interest. For this reason, the current chapter describes a follow-up study conducted using a survey methodology. Specifically, the 21 recommendations from students in our interview study (Chapter 9) were:

- ***Topics for learning accessibility:*** Gathering software requirements related to accessibility, disability etiquette, incorporating accessibility in the software development cycle, Deaf culture, accessible technologies or devices, authoring website content, testing software for accessibility, and communication preferences of different individuals with a disability.
- ***Resources:*** Examples of accessible technologies, APIs or programming frameworks with accessible features, books or websites on accessibility, list of professors that specialize in accessibility, guest speakers with a disability, accessibility guidelines and regulations, automated software accessibility evaluation tools, online courses or tutorials, list of organizations that support individuals with a disability.

- ***Course structure:*** Add accessibility requirements within existing course work and classes, add a required accessibility course for my degree, create an elective course that counts towards my major, and ability to take courses outside the college that will count towards my major.

10.1.1 Research Question

To better prioritize these recommendations, we conducted a survey of a larger set of senior-level students to answer the research question:

RQ 7. What educational resources or instructional methods do students wish they would have had, to better prepare them to create accessible technologies?

10.1.2 Hypothesis

Related work suggested that computing degree programs tended towards introverted learning behaviors [22], whereby information was primarily gained through online resources and factual information rather than other people [18]. Furthermore, prior studies highlighted how computing students regularly acquired knowledge through self-directed learning [86] and the Internet [37]. As such, it was hypothesized that students would primarily request resources that could support them in this style of learning, such as through automated evaluation tools and programming libraries.

10.2 Methodology

In creating the questionnaire, we piloted a combination of Likert-scale and ranking questions. During six pilot studies, we found that participants ranked and scored items differently. For instance, students assigned high Likert-scale scores for multiple items, but would only include a subset within their top ranked choices. As such, our analysis included a triangulation of students' Likert scale responses, ranked questions, and open-ended responses.

- ***Likert-scale items:*** Students were asked to assign Likert-scale agreement scores to each recommendation within the three categories (***topics for learning accessibility, resources, course structure***). The statement for the three overall questions was, *'I believe this [Topic/Resource/Course structure] would be important in preparing me to create accessible technologies in my career.'*. The Likert scale response options ranged from from *1=strongly disagree, 3=neither agree nor disagree,* and *5=strongly agree.* To minimize ordering effects, all suggestion items were randomized per participant.

- ***Ranked questions:*** After each category of recommendations, students were asked to indicate their top three choices. A total of three questions were asked, *'Please indicate the top three items above that you believe would best prepare you in creating accessible technologies in your career'*.
- ***Open-ended questions:*** After each category of Likert-scale responses and ranked questions, students were asked, *'Please explain why you chose the three items above'*.

10.2.1 Participant Recruitment

Participants were recruited through email and in-person events where they were compensated with $10 for participation. To be eligible for participation, students had to be in an undergraduate computing program with less than one year remaining to complete their degrees. Each electronic questionnaire took approximately 10 minutes to complete. A total of 114 undergraduate senior students from Rochester Institute of Technology completed the survey during March and April 2019. Of the 114 students, 96 were male, 16 were female, and 2 were non-binary.

10.2.2 Quantitative Analysis

As discussed in Section 10.2, the survey included a triangulation of Likert-scale, ranked, and open-ended questions. We determined students' top-ranked choices through a weighted average of the responses. In the ranked questions, students were able to select their top three choices for each category. As such, the lowest ranking was assigned a weight of one and the highest a weight of three. The possible ranges for the weighted scores could be a minimum of zero and a maximum of three.

Next, we determined whether students' selections were significantly different from one another. We conducted a Kruskal-Wallis H test for each category *(Topic, Resources, Course structure)* of Likert-scale responses. If a significant difference was observed, we conducted a follow-up pairwise Dunn's post hoc test, with Bonferroni correction, to isolate which recommendations were scored significantly different from one another.

Finally, four researchers qualitatively coded the open-ended responses in pairs. They independently assigned descriptive annotations [111] to each response and reconvened to share their findings. The analysis of the open-ended responses allowed us to further understand students' preferences.

10.3 Results

In an analysis of students' Likert scale responses, we found that all categories had at least one pair of items with significant differences (refer to Table 10.1). We discuss the results of each category in the subsections below. The weighed average rankings of all categories will be discussed in the following subsections. All raw rankings are included in Appendix H.

Table 10.1: Kruskal-Wallis H test indicated that all categories contained at least two items with significant differences (α=0.05)

Category	**Test Statistic**	**p-value**
Topic	$X^2(7)$=76.004	p<0.001*
Resources	$X^2(8)$=197.740	p<0.001*
Course structure	$X^2(3)$=62.692	p<0.001*

Asterisk (*) indicates significance at $\alpha = 0.05$.

10.3.1 Topics for Learning Accessibility

There were eight topic suggestions: *Gathering software requirements related to accessibility, disability etiquette, incorporating accessibility in the software development cycle, Deaf culture, accessible technologies or devices, authoring website content, testing software for accessibility, and communication preferences of different individuals with a disability.* When calculating the weighted average for the rankings of these topics, the top three selections were: *Testing software for accessibility* ($\bar{x}$=1.377), *gathering software requirements related to accessibility* ($\bar{x}$=1.298), and *incorporating accessibility in the software development life cycle* ($\bar{x}$=0.833).

A post-hoc Dunn's test of the Likert-scale responses indicated that the top-ranked choice, *testing software for accessibility*, was significantly different from all other ***Topic*** choices, except for the second-ranked item, *gathering software requirements related to accessibility.*

In the open-ended question, students explained that they preferred *'practical learning'* tools instead of fully understanding the reasoning behind accessibility practices. Students wanted *'vetted tools'* that they could directly use. One survey participant explained:

> *As important as understanding disability background and culture is, software engineers need to rely on development tools to create technology that the disabled can use. It is easier to follow specifications than to understand the reasons behind the inclusion of said specifications.*

Students also explained that lower-ranked ***Topic*** choices would be *'unnecessary and unproductive'*, because they can be *'learned outside the classroom'* and would not produce tangible results. These findings corroborate interview findings, whereby students identified a lack of detailed guidance in educational and work environments on what would be necessary to directly create accessible technologies.

10.3.2 Resources

There were nine resource suggestions gathered during interviews that were further prioritized in the surveys: *Examples of accessible technologies, APIs or programming frameworks with accessible features, books or websites on accessibility, list of professors that specialize in accessibility, guest speakers with a disability, accessibility guidelines and regulations, automated software accessibility evaluation tools, online courses or tutorials, list of organizations that support individuals with a disability.* A calculation of the weighted average of the responses resulted in three top choices: *APIs or programming frameworks with accessible features* ($\bar{x}$=1.535), *examples of accessible technologies* ($\bar{x}$=1.246), and *accessibility guidelines and regulations* ($\bar{x}$=0.877). With exception of *automated software accessibility evaluation* *tools*, students rated all top three choices significantly different than the five lower-rated choices, when tested through a Dunn's test.

In open-ended questions, students stated that they preferred ***resources*** that they could independently use. They preferred quick solutions, such as *'built-in accessibility'* within APIs or programming languages, *'online simulators'*, guidelines, and automated evaluation tools. Participants stated that such resources could help diminish *'the need of having someone with a disability there to evaluate it for you'*.

In addition, participants viewed lower-ranked items as secondary or back-up resources. They did note that the lower-ranked, human-centric, resources were *'good and important to have'* but that *'students [would] not use them or not be as interested in them'* preferring to *'learn by example and documentation, as well a having online validators.'*

10.3.3 Course Structure

The ***Course structure*** category contained four choices: *Add accessibility requirements within existing course work and classes, add a required accessibility course for my degree, create an elective course that counts towards my major, and ability to take courses outside the college that will* *count towards my major.* The top three ranked items, identified through their weighted average, were: *Create an elective course that counts towards my major* ($\bar{x}$=2.266), *add accessibility requirements within existing course work and classes* ($\bar{x}$=1.706), and *ability to take courses outside the college that will count towards my degree* ($\bar{x}$=1.422).

In Likert-scale responses, the top-ranked option, *create an elective course that counts towards my major*, was significantly different than all other options. In open-ended responses, participants explained that the option for an elective course was ideal because it would allow those who were *'truly interested'* in accessibility to take the course. Students did not want to be *'forced to learn more about it'*. Furthermore, survey respondents explained that accessibility was *'irrelevant to their majors'*, such as one participant who explained that elective courses were preferred over requirements for accessibility:

> *Requirements get iffy, personally I don't like required courses when they are absolutely irrelevant to my degree/major. However, if someone was passionate about creating accessible technologies, and it was within the scope of the field they want to work in, they would "want" to take these courses.*

Opting-in to accessibility education would be preferred because not everyone would be using the information in their careers:

> *As important as accessibility is, not everyone is planning to work in fields that work with accessibility technologies, so I would err on the side of making the course materials an elective rather than required.*

10.4 Discussion and Conclusion

A unexpected finding from the surveys was that respondents were largely unmotivated to learn more about accessibility regardless of the recommendations proposed by their peers. Elective courses in the ***course structure*** category were the most preferred as students did not want required courses on the topic. This was in accordance with the results of the interviews in Chapter 9, in which students indicated that they were unmotivated to further their learning after the HCI course. In that prior interview based study, students mentioned a number of reasons for not pursuing further study of accessibility, including *not seeing accessibility as an essential skill to all computing career paths* (refer to: Chapter 9).

Again, in this survey-based study in the current chapter, we found that students preferred ***resources*** that did not rely on human interactions (e.g., a participant noting that online resources are preferred as they diminished *'the need of having someone with a disability there to evaluate it for you'*) and ***topics*** that could be readily applied within their course projects. ***Topics*** regarding *etiquette, communication preferences, and Deaf culture* were seen as less necessary (e.g., a participant noting that *'It is easier to follow specifications than to understand the reasons behind inclusion of said specifications.'*). Students indicated that the preferred ***resources*** and ***topics*** were practical as they could directly support them in their class projects.

A preference for online sources was further deliniated in open-ended responses (e.g., participants noting the need for *'built-in accessibility APIs'* and *'online simulators'*). Preferences for online resources have also been observed in related work [18, 22, 87] and were further corroborated during our interviews where students described a *learn-it-on-your-own approach* to computing (refer to: Chapter 9). While online resources may be useful for other computing topics, related work has indicated that accessibility guidelines and automated testing tools can be unreliable or difficult to interpret [126, 130, 152].

Overall, the findings from the survey reinforce the general results of the interview discussed in Chapter 9: instructors must first address extrinsic factors that motivate the need for accessibility. **Whereas prior researchers have highlighted the need to appeal to intrinsic motivators [32, 110, 112], our findings suggest that extrinsic factors must be addressed first** (e.g., survey participant noting *'As important as accessibility is, not everyone is planning to work in jobs or fields that work with accessibility technologies.'*).

Chapter 11

Conclusions and Future Directions

11.1 Conclusion

While preparing future computing professionals in accessibility is important to the development of equitable and innovative technologies, prior work did not discern which educational methods were most effective [100]. This dissertation provides a systematic cross-sectional and longitudinal evaluation of students' learning when exposed to one of four ***conditions***: *lectures, projects, stakeholders, or team members.* Our mixed methods study involved hypothesis testing, qualitative coding, and grounded theory to holistically understand what factors inside and outside the classroom influenced students' learning of accessibility. We evaluated students' learning throughout three years (spring 2016-2019), resulting in a review of the four ***conditions*** throughout 14 courses and seven distinct professors. While existing literature includes an analysis of computing students' learning of accessibility in one or two courses, this dissertation outlines a systematic analysis across multiple courses and instructors. To the best of our knowledge, this is the first systematic evaluation of accessibility instruction within a computing degree program.

In our short-term analysis, which compared students' survey responses immediately before and after the HCI course, we found that students who had *stakeholder interactions* obtained the greatest number of significant changes at the short-term: *prosocial sympathy, awareness, knowledge, and consideration of individuals with a disability.* In the long-term, when surveying students again 12-18 months after the course, we found that only students who had completed a *project* or had a *team member with a disability* sustained significant changes in their *knowledge* of implementation techniques. All other observations from the short-term, such as the *stakeholder* condition yielding greater *awareness*, were no longer observed in the long-term.

The analysis of the interviews, surveys, and project reports provided context for the longitudinal results in Chapter 7. Students were largely unmotivated to continue their learning of accessibility due to: *not being required to consider accessibility, not seeing it essential to a career in computing, and challenges amid a learn-it-on-your-own computing approach*, which is common in the computing field. Much current computing education research has focused on ways to increase students' intrinsic motivations and empathy towards individuals with a disability, however, our findings suggest that educational interventions must *first* address external factors in order to engage students on the topic. That is, educational interventions must reinforce the expectation that a computing profession requires consideration of inclusion and accessibility. To overcome challenges of a *learn-it-on-your-own* approach, instructors must actively engage and mentor students on the topic.

An understanding of what teaching methods are most effective is crucial to the future integration of this content within curricula. The knowledge contributions presented in this dissertation can be used to directly inform university budgets and curriculum initiatives. Future avenues for this work focus on understanding the impact of classroom instruction, in conjunction with, the external factors discovered in 1-on-1 interviews.

As discussed in Chapter 1, the main contributions of this work also included the documentation of the data collection and analysis methods to support study replication. The appendices of this document contain all the appropriate information for replication of this study. This includes all teaching and evaluation materials. Continued systematic evaluations and replications of computing education research are necessary: In a review of computing education research from 2009 to 2019, Hao et al., were unable to identify any systematic evaluation of accessibility computing efficacy [48]. By outlining all of our processes, we hope that this document will serve as a point of comparison for future endeavors.

11.2 Possible Future Steps

There are many questions motivated by this dissertation that may be explored by future researchers and later stages of this NSF-funded project. Possible future steps can include the continued data collection of senior-level students and students within the *lectures and team member* condition. There are also three additional initiatives that can build upon this dissertation work: *researching the extrinsic factors that influence students' perceptions of accessibility, investigating how accessibility can be taught throughout the curriculum, and replicating the study at other universities.*

11.2.1 Research of Extrinsic Factors

In the research outlined in this dissertation, we found that extrinsic factors were important to students when determining which computing topics to further their learning on. Given the importance of these factors, it would be appropriate for a future study to specifically investigate the potential of interventions that may address students' extrinsic motivations. For example, interventions that counter a *learn-it-on-your-own* computing approach can be selected. This may include participation in a project mentorship activity (e.g., NSF Research Experiences for Undergraduate Students) or interactions with computing professionals who apply accessibility knowledge in their career. During interviews, students identified these experiences as motivating them to maintain their knowledge of accessibility (refer to: Chapter 9).

11.2.2 Accessibility Education Throughout the Curriculum

This dissertation has specifically investigated the potential impact of several educational interventions which were focused upon a single HCI course delivered to students in computing majors. However there are other ways in which such educational interventions or changes could be implemented throughout the curriculum. For instance, Waller et al., proposed a method for incorporating accessibility throughout a computing curriculum [140].

A future avenue for this work could involve the investigation of how accessibility can be integrated throughout a curriculum and whether this can promote students to regularly consider accessibility throughout their work. As discovered in Chapter 9, students' build their career expectations based on the curriculum and these perceptions remain beyond initial work experiences (e.g., with seven out of 16 students being required to apply accessibility during internships, but only one of these students indicating it would be necessary for all computing professionals). Future initiatives for integrating accessibility from the curriculum can be informed by the results of students' prioritized topics and methods discussed in Chapter 10.

11.2.3 Replicating the Study at Other Universities

Finally, future work can help identify whether the educational interventions discussed in this dissertation can be replicated at another university, and whether they would result in a similar efficacy. As a first step, before expanding the study to another university, researchers could begin by investigating this question by evaluating Computer Science students at Rochester Institute of Technology (RIT) who do not receive exposure to the teaching ***conditions***. An analysis of Computer Science students' learning could reveal the magnitude of changes that arise from the environment at RIT. In Chapter 8 for instance, we found that students were more likely to consider individuals who were deaf or hard of hearing than have been reported in existing literature [101]. An evaluation of students' learning outside the conditions, may help reveal whether any lessons may be implicitly gained through the RIT environment.

Next, a logical step would be to implement the educational interventions discussed in this dissertation within the context of a Computing course at another university. The simplest first step would be to evaluate students' short-term changes (pre vs. post) when exposed to the *stakeholder* condition. Such a study would help determine whether the impact of the interventions measured at RIT would be generalizable to a different university context.

11.3 Summary

The consideration of accessibility and inclusion is a core component of computing professionals' role. Through the development of accessible technologies, computing professionals mediate the widespread availability of vital information and services, e.g., health, economic opportunities, and personal security. In Chapter 2, we also discussed various mainstream accessible technologies which have lead to disruptive innovations that have redefined the way we interact with technology under various permanent, temporary, and situational impairments, e.g., voice-first technologies and video captioning.

The empirical research outlined in this dissertation measures the efficacy of various teaching interventions to help guide future educational initiatives. These findings may be useful for organizations such as the Association for Computing Machinery and Accreditation Board for Engineering Technology, which develop curriculum guidelines informed by computing professionals' code of ethics. The findings contained within this dissertation may also be useful for broader organizations advocating for additional accessibility education within the computing curriculum. Furthermore, our systematic evaluation of teaching interventions can provide guidance for future instructors who wish to add accessibility content within their courses.

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Appendices

Appendix A

Questionnaire

A questionnaire developed by Huenerfauth et al. [2015] [54] is the basis of the quantitative dataset of this dissertation. The questionnaire by Huenerfauth et al. contains 13 sections to assess students' accessibility awareness, knowledge, and attitudes.

Survey

A team of faculty members at [university name] ([faculty names]) are investigating how to improve courses on human computer interaction and related topics. The purpose of this survey is to help us understand student's awareness of the needs of users of technology. This voluntary survey is confidential and will not affect your course grade in any way.

Please note that once you start the survey, you will not be able to go back.

1. Enter your first and last name. This survey requests that you provide your name and identity so that results can be analyzed over time; however, your name and identify will remain confidential (only available to the investigators on the research team)

2. What is your [university name] email ID? This will help identify you in case of multiple students having the same name.

For the following questions (Questions 3 and 4), refer to the following scenario:

In order to meet recently revised federal legislation, the state of New York has charged your organization with the task of developing new electronic voting kiosks. In the past, all voting was conducted in person or via mail-in ballot.

Each registered voter was mailed a voting card. The card was presented when the voter goes to the designated voting precinct for in-person voting. No ballots were given to voters without their voting cards. These voting cards will continue to be used with the new kiosks.

The new system focuses on in-person voting. Each registered voter who wishes to vote in-person must be able to do so independently. The new system needs to be very secure in terms of making sure that each person can vote no more than once, that their votes are accurately counted, and that the votes are archived securely. Also only the precinct officials and any other general election officials should have access to the results at any time. Each person's ballot must be formatted in a consistent manner, which conforms to state ballot format standards. After the voter finishes voting, the kiosk prints the ballot, which is submitted to the precinct official for archiving. Only in-person voting is supported in the new system.

The kiosks need to respond quickly to the voting selections made by the voters. Also the vote count reports need to be well organized and clearly formatted. The voting official (at the precinct) must verify the vote counts at his/her station by double-checking the totals from all voting kiosks three times. For all 3 times, the totals must be the same. If there is a discrepancy, then the precinct official must count the votes by hand, and submit the results to the county voting office in person.

3. If you are to design the user interface for the system, what are the key points that you need to keep in mind in terms of the task of voting itself?

4. What potential voters will you test the kiosk prototype with in order to gain feedback on the new kiosk design?

5. Listed below are a number of statements that are said to describe what people think about different disabled people. Usually, what we think about individuals depends on how well we know them. However, we would like to know what you think in general. Please read each statement carefully and circle what response best describes how you usually feel. *If you're not sure about an item, go ahead and answer it to the best of your ability. If there are items you would rather not answer, just leave those blank, or write a comment about those items at the bottom of the page.*

	Agree very much	Agree pretty much	Agree a little	Disagree a little	Disagree pretty much	Disagree very much
It is rewarding when I am able to help	○	○	○	○	○	○
It hurts me when they want to do something and can't	○	○	○	○	○	○
I feel frustrated because I don't know how to help	○	○	○	○	○	○
Contact with a disabled person reminds me of my own vulnerability	○	○	○	○	○	○
I wonder how I would feel if I had this disability	○	○	○	○	○	○
I feel ignorant about disabled people	○	○	○	○	○	○
I am grateful that I do not have such a burden	○	○	○	○	○	○
I try to act normally and ignore the disability	○	○	○	○	○	○
I feel uncomfortable and find it hard to relax	○	○	○	○	○	○
I am aware of the problems that disabled people face	○	○	○	○	○	○
I can't help staring at them	○	○	○	○	○	○
I feel unsure because I don't know how to behave	○	○	○	○	○	○
I admire their ability to cope	○	○	○	○	○	○
I don't pity them	○	○	○	○	○	○

	Agree very much	Agree pretty much	Agree a little	Disagree a little	Disagree pretty much	Disagree very much
After frequent contact, I find I just notice the person not the disability	◯	◯	◯	◯	◯	◯
I feel overwhelmed with discomfort about my lack of disability	◯	◯	◯	◯	◯	◯
I am afraid to look at the person straight in the face	◯	◯	◯	◯	◯	◯
I tend to make contacts only brief and finish them as quickly as possible	◯	◯	◯	◯	◯	◯
I feel better with disabled people after I have discussed their disability with them	◯	◯	◯	◯	◯	◯
I dread the thought that I could eventually end up like them	◯	◯	◯	◯	◯	◯

6. Please enter any comments that you have here regarding any of the statements in Question 5. This is optional.

7. For various reasons, it can be difficult for some people to use current computing technology. You may have personal experience with this (such as through a family member or friend) or you may be aware of this through other means. Please indicate whether you are familiar with some specific challenges that people have when using computers, mobile devices, and the web – or whether you or someone you know well has personal experience with this -- for the following people:

	I have knowledge of this	I have personal experience with this
People who have low vision	◯	◯
People who are blind	◯	◯
People who are deaf or hard of hearing	◯	◯
People with autism	◯	◯
People with learning disabilities	◯	◯
People with intellectual disabilities	◯	◯
People with motor or movement disabilities	◯	◯
Older people	◯	◯

8. If you answered "I have personal experience with this" to any of the items in Question 6, please explain:

9. I know how to design websites and software to ensure that it is accessible for the following people:

	I have heard or read about this	I have done this before
People who have low vision	◯	◯
People who are blind	◯	◯
People who are deaf or hard of hearing	◯	◯
People with autism	◯	◯
People with learning disabilities	◯	◯
People with intellectual disabilities	◯	◯
People with motor or movement disabilities	◯	◯
Older people	◯	◯

10. I understand how the following aspects of website design affect people with disabilities:

	I'm familiar with this issue	I have taken this issue into account to make the site more accessible for people with disabilities
The use of cascading style sheets (CSS)	○	○
The use of alt text for images	○	○
The use of headings for tables	○	○
The labels on elements of forms	○	○
The content of the underlined text of hyperlinks	○	○
The use of captions for videos or sounds	○	○
The use of headings (H1, H2, etc.)	○	○
The use of event handlers (e.g., onFocus)	○	○
The use of different colors on a page	○	○
The use of diagrams or images to accompany text	○	○

11. I understand how the following aspects of software or mobile-app design affect people with disabilities:

	I'm familiar with this issue	I have taken this issue into account to make it more accessible for people with disabilities
Ensuring compatibility of the user-interface with screen reader technology	◯	◯
Supplying higher resolution or vector graphics to support magnification or enlargement	◯	◯
Providing information content redundantly through both visual and audio channels	◯	◯
Providing access to all elements of the user interface via keyboard commands	◯	◯
Limiting the complexity of text information content on the user-interface	◯	◯
Avoiding the use of messages that require a response from the user in a fixed time limit	◯	◯

12. I have previously been involved in the design/development of websites or software.

◯ Yes

◯ No

13. When I worked on the design/development of a website or software, I considered issues of users with diverse abilities in my work:

- ◯ Yes
- ◯ No

Appendix B

Institutional Review Board

This research was approved by the Institutional Review Board. This includes three IRB Form C approvals: one for the initial analysis of the courses, an amendment for recruitment of Computer Science students through flyers, and an interview study of senior students.

R·I·T

Rochester Institute of Technology

RIT Institutional Review Board for the
Protection of Human Subjects in Research
141 Lomb Memorial Drive
Rochester, New York 14623-5604
Phone: 585-475-7673
Fax: 585-475-7990
Email: hmfsrs@rit.edu

Form C
IRB Decision Form

TO: Stephanie Ludi

FROM: RIT Institutional Review Board

DATE: **July 10, 2015**

RE: Decision of the RIT Institutional Review Board

Project Title – Ethical Inclusion of People with Disabilities through Undergraduate Computing Education

NSF Submission 1540396

The Institutional Review Board (IRB) has taken the following action on your project named above.

☒ Exempt _46.101 (b) (1)_

Now that your project is approved, you may proceed as you described in the Form A.

You are required to submit to the IRB any:

- **Proposed** modifications and wait for approval before implementing them,
- Unanticipated risks, and
- Actual injury to human subjects.

Heather Foti, MPH
Associate Director
Office of Human Subjects Research

R·I·T

Rochester Institute of Technology

RIT Institutional Review Board for the
Protection of Human Subjects in Research
141 Lomb Memorial Drive
Rochester, New York 14623-5604
Phone: 585-475-7673
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Form C
IRB Decision Form

TO: Matt Huenerfauth

FROM: RIT Institutional Review Board

DATE: **March 30, 2018**

RE: Decision of the RIT Institutional Review Board

Project Title – Ethical Inclusion of People with Disabilities through Undergraduate Computing Education

Amendment Changes
1. Incentive
2. PI Change

The Institutional Review Board (IRB) has taken the following action on your project named above.

☒ Exempt _46.101 (b) (1)_

Now that your project is approved, you may proceed as you described in the Form A.

You are required to submit to the IRB any:
- **Proposed** modifications and wait for approval before implementing them,
- Unanticipated risks, and
- Actual injury to human subjects.

Heather Foti, MPH
Associate Director
Office of Human Subjects Research

R·I·T

Rochester Institute of Technology

RIT Institutional Review Board for the
Protection of Human Subjects in Research
141 Lomb Memorial Drive
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Phone: 585-475-7673
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Form C
IRB Decision Form
FWA# 00000731

TO: Paula Garcia, Vicki Hanson

FROM: RIT Institutional Review Board

DATE: **June 21, 2018**

RE: Decision of the RIT Institutional Review Board

Project Title – Barriers in Undergraduate Computing Education when Designing for Individuals with Disabilities

The Institutional Review Board (IRB) has taken the following action on your project named above.

☒ Exempt _46.101 (b) (2)_

Now that your project is approved, you may proceed as you described in the Form A.

You are required to submit to the IRB any:

- **Proposed** modifications and wait for approval before implementing them,
- Unanticipated risks, and
- Actual injury to human subjects.

Heather Foti, MPH
Associate Director
Office of Human Subjects Research

Revised 08.17.2017

Appendix C

Senior Semi-Structured Interviews

Semi-structured interviews will be conducted with senior students to identify the longitudinal efficacy of the teaching conditions and the barriers to existing methods for teaching accessibility. The interviews contain nine questions regarding usability concepts, experiences working with diverse users, barriers in existing courses, and students' preparedness for addressing accessibility barriers in their careers.

SCREENER

Barriers in Undergraduate Computing Education when Designing for Individuals with Disabilities

Thank you for responding to the research project announcement regarding computing education. The purpose of this research project is to study the barriers that limit computing students from considering accessibility within their work. The study will be conducted in GOL-1620, the Center for Accessibility and Inclusion, at Rochester Institute of Technology.

Today we invite you to participate in a short survey to see if you are eligible to participate in the 45-minute interview. This survey is expected to take two minutes to complete and will be available until October 30th, 2018. If you qualify, we will email you to schedule the interview. Should you wish to participate in the interview, you will be compensated with $20 for your 45-minutes of assistance.

All responses will remain confidential. If you have any questions, please contact Paula Garcia at pxg5962@rit.edu.

OK

If participant selects the highlighted items, they are redirected to the disqualification page.

* 1. Are you a student at Rochester Institute of Technology?

- Yes (selected)
- No
- Other (please specify)

* 2. What is your major?

Computer Science

* 3. What is your academic program?

- Associate
- Undergraduate (selected)
- Graduate
- PhD
- Other (please specify)

* 4. What is your current year of study?

- 1st year (selected)
- 2nd year
- 3rd year
- 4th year
- 5th year
- Other (please specify)

NEXT

SCREENER: *continued*

5. Do you have experience designing software for individuals with disabilities?

- ○ Yes
- ✔ No
- ○ Other (please specify)

* 6. Please select the gender you identify with:

- ○ Male
- ✔ Female
- ○ Other (please specify)

* 7. Approximately how many team projects have you completed within your courses?

- ○ 0
- ✔ 1-3
- ○ 4-6
- ○ 6+

8. Please enter your RIT e-mail so we can contact you if you are eligible:

PREV DONE

7 of 8 answered

SCREENER: DISQUALIFICATION PAGE

Barriers in Undergraduate Computing Education when Designing for Individuals with Disabilities

Thank you for completing our survey. Unfortunately you are not eligible to participate in this study at this time. This study is limited to undergraduate computing students at Rochester Institute of Technology, who are in their final year(s) of study.

DONE

SEMI-STRUCTURED INTERVIEW QUESTIONS

BACKGROUND
1. What steps do you take to improve the usability of software?
    a. Would you describe yourself as a beginner, experienced, or very experienced in addressing usability issues in software? Why?
    b. What skills do usability experts have?
    c. What courses or activities have you done to gain experience in usability?

EXPOSURE TO DIVERSE USERS
2. What target markets have you developed software solutions for?
3. Is there a specific target market that you have enjoyed working with? Why?
    a. How did you gain access to [target market]?
4. When was the first time that you considered creating software for individuals with different abilities from your own? What motivated you to consider [the solution]?

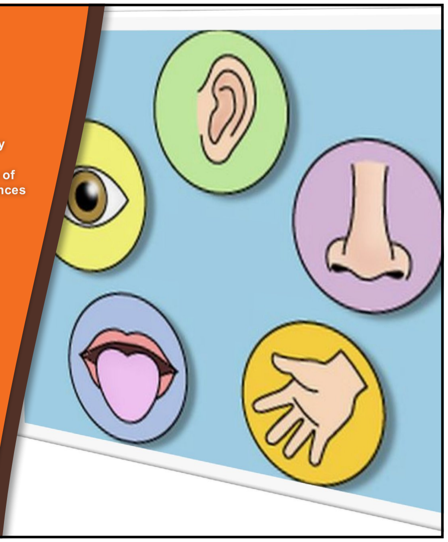
BARRIERS IN COMPUTING EDUCATION
5. Are you currently enrolled in a Senior Project course?
    a. What is your project topic?
    b. What challenges have you faced thus far?
    c. What are your projects' target markets? How do their characteristics differ from your own?
    d. Have you considered features to improve the accessibility for individuals with disabilities?
6. What additional team projects have you completed during your time at RIT?
    a. Have any of the projects included features targeted at individuals with disabilities?
    b. What made you consider these features? OR What dissuaded you from considering individuals with disabilities?
    c. Can you describe the course?
    d. Is there anything the professor could have improved upon to help you achieve your initial goals?

ACCESSIBILITY EDUCATION AT RIT
7. Can you recall a time when you saw someone using an accessibility feature or technology that you were not exposed to? How did the tool help them achieve their goals?
8. Do you feel prepared to address accessibility barriers in computing once you graduate? Why?
    a. What type of accessibility barriers could you address, and how?
    b. Are there any accessibility barriers you wish you knew how to address? What type of information would you need to feel prepared to address [the barrier]?
    c. Have any of your courses at RIT increased your knowledge of accessibility?
    d. Have you participated in any activities at RIT that increased your knowledge of accessibility?
9. How has RIT's focus on accessible education, such as interpreters and flipped classrooms, changed the way you think about computing?

Appendix D

Accessibility Lecture Content Slides

The accessibility lecture content slides are provided to instructors at the start of the semester. The slides are designed to span one week of the course and are split into three sections.



R·I·T

Rochester Institute of Technology

The B. Thomas Golisano College of Computing and Information Sciences

Human Abilities: Senses

R·I·T

Outline

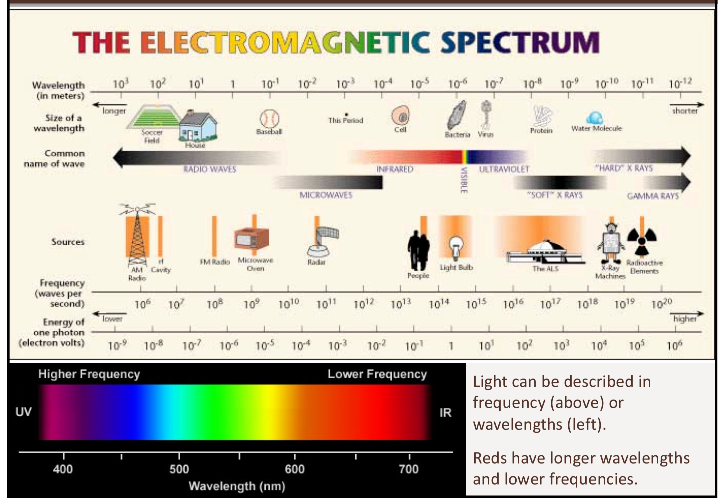
- Senses
  - Vision
  - Hearing
  - Touch
  - Smell
- Motor System
- Cognitive Abilities

R·I·T

HUMAN VISION 101

Visual resolution

R·I·T

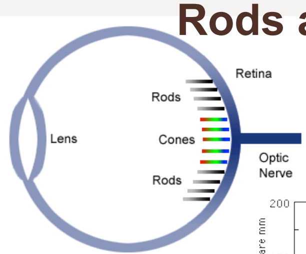


Light can be described in frequency (above) or wavelengths (left).

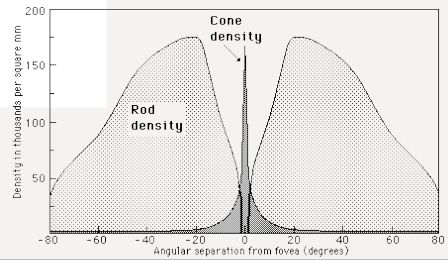
Reds have longer wavelengths and lower frequencies.

R·I·T

Rods and Cones



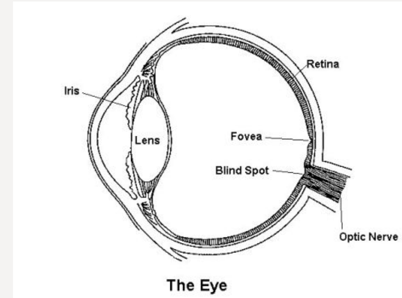
Rods: best at detecting brightness; we depend on them in low-light conditions
Cones: three different types, which respond to different wavelengths of light



R·I·T

Physiology

- Fovea: Center of visual field on retina, high resolution vision



R·I·T

VISUAL IMPAIRMENTS

Resolution and Clarity

R·I·T

Definitions, Prevalence

Definitions used in some U.S. laws:

- "Blindness"
  Visual acuity of 20/200 or worse in the best eye with best correction, or a visual field of 20 percent or less
- "Partial sight (low vision)"
  Visual acuity greater than 20/200 but not greater than 20/70 in the best eye after correction

How common is this?

- 5% of American children (and 20% of people over age 65) have a serious eye disorder.

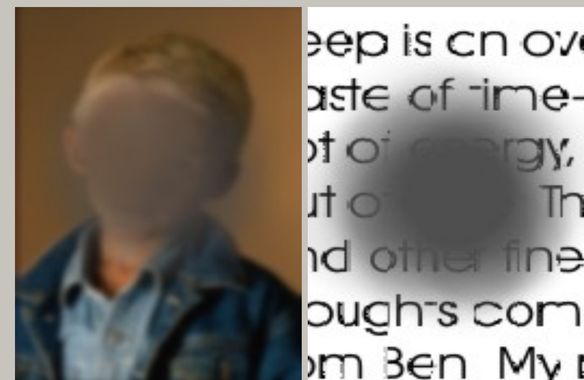
R·I·T

Examples of Low-Vision Conditions

- Macular Degeneration
- Glaucoma
- Diabetic Retinopathy
- Cataracts

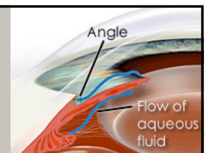
Macular Degeneration

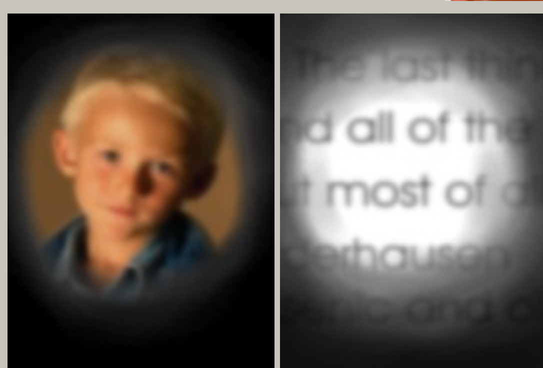
Gradual thinning or sudden damage (leaking blood vessel) of the macula, which is at the center of the retina, at the back of the eye. Loss of central vision.



Glaucoma

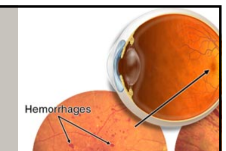
Increase in pressure of the fluids inside the eye, due to a problem with the drainage structures at edge of iris.
Loss of peripheral vision, blurring of central vision.

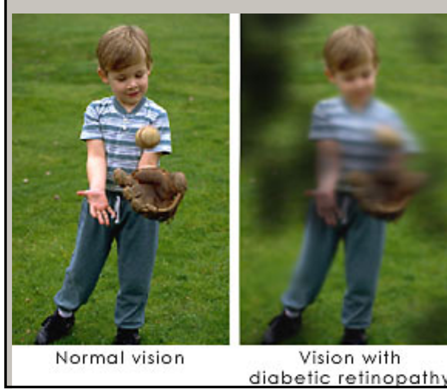


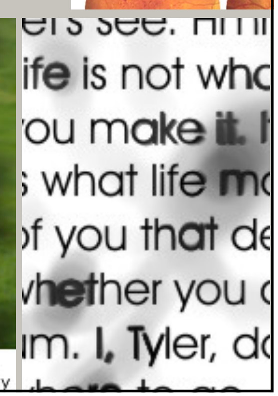


Diabetic Retinopathy

One of the effects of long-term diabetes can be the leaking of retinal blood vessels, causing dark patches in the field of vision where the leaks occur.

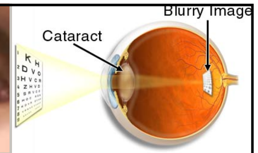






Cataracts

Areas of opacity in the lens, causes blurred or hazy effect. It's worse in bright light.



R·I·T

Other Causes of Vision Impairments

- Genetically Determined
  - Albinism (lack of pigment, needed in the eye)
  - Retinitis pigmentosa
  - Optic atrophy
  - Cataracts
  - Severe myopia associated with retinal detachment
  - Lesions of the cornea
  - Abnormalities of the iris
  - Microphthalmia
  - Anophthalmia
  - Buphthalmos (Glaucoma)
- Acquired Disorders
  - Exposure to drugs
  - Radiation
  - Prenatal infections
  - Diseases
  - Xeropthalmia
  - Prolonged use of oxygen with premature infants
  - Cortical visual impairment
  - Trachoma
  - Macular degeneration

R·I·T

VISUAL IMPAIRMENTS

Age-Related Vision Loss

R·I·T

Age-Related Vision Impairment

- More likely for an older adult to have some kind of vision impairment, e.g., lens abnormalities:
  - Myopia/near-sightedness
  - Presbyopia/far-sightedness
- Leading age-related cause of vision loss in U.S. is macular degeneration (internationally, it is cataracts).
- Over time, lens hardens, accommodation slows
  - So, it is more difficult for someone to focus.
- Clouding of fluid in eye increases problems with glare in bright light, leading to a decline in:
  - Number of hues distinguished
  - Contrast sensitivity

R·I·T

Signs of Vision Problems in Older Adults

Older adults may not realize or acknowledge changes in their vision, but there may be signs:

- Bump into things.
- Move hesitantly or walk close to the wall.
- Grope for objects or touch them in an uncertain way.
- Squint or tilt the head to see.
- Request more or different kinds of lighting.
- Hold books or other reading matter close to the face.
- Have trouble making out faces, the lettering on signs
- Trip on area rugs.

R·I·T

VISION IMPAIRMENTS

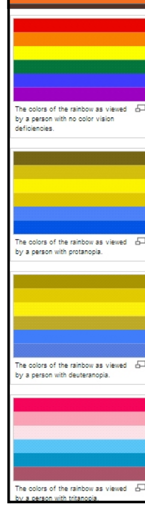
Color sensitivity

R·I·T

Color Blindness

- Approximately 8% of Caucasian male population is color deficient; some estimates higher (8-10%)
  - Occurrence in women is approximately 1%
- Red/green insensitivity is most common
- Everyone loses color vision in low light
- Possible to acquire color blindness through damage to the retina, optic nerve, or brain.
- Some migraine sufferers experience it prior to headache.

R·I·T



Inherited Color Blindness

Monochromacy: total color blindness, very rare.

Dichromacy:

One of the three basic color mechanisms is absent or not functioning. It is hereditary and sex-linked, affecting mostly males.

RG **Protanopia:** No red cones. Red appears dark; affects red-green hue discrimination.

RG **Deuteranopia:** No green cones. Affects red-green hue discrimination.

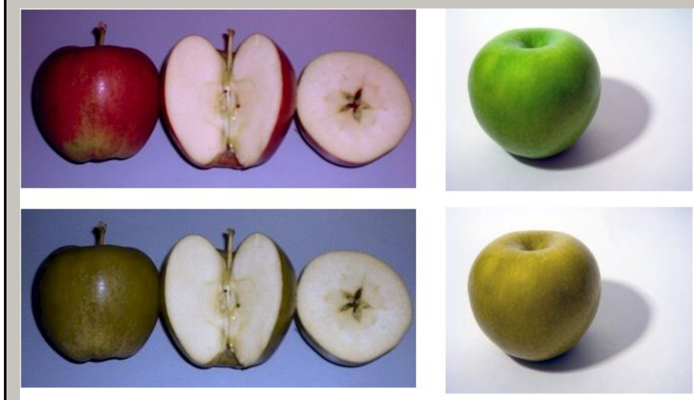
YB **Tritanopia:** Very rare. No blue cones. Affects yellow-blue discrimination.

Anomalous Trichromacy: More common. One of the cone pigments is altered in its spectrum. Impairment, but not full loss.

Most RG
Some YB

Color Blindness

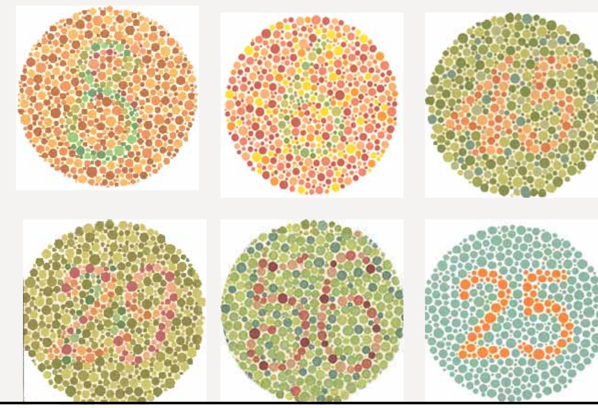
Typical Color Vision



Deuteranopia

R·I·T

Ishara Dot Tests



R·I·T

Considering the user's abilities is important.

FLORIDA

Air crash linked to colorblind pilot

TALLAHASSEE — A FedEx plane crash last year may have been caused by a colorblind co-pilot's difficulty in seeing red warning lights, federal investigators say.

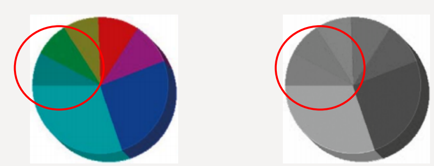
The National Transportation Safety Board is investigating whether William Frye failed to see red runway lights that indicated the cargo jet was dangerously low, the St. Petersburg Times reported Friday.

The Boeing 727 crashed a half-mile short of the runway at the Tallahassee airport in July 2002 as it was coming in for a landing. Its three-member crew escaped serious injury.

R·I·T

Color Blindness - Applied

- Look at your layout in **grayscale**. If you can't see intended differences, chance are neither can color blind individuals



R·I·T

Color Blindness - Applied

- Use distinctive colors

FIGURE 5.12
The most distinctive colors. Each color causes a strong signal on only one color-opponent channel.

R·I·T

Outline

- Senses
  - Vision
  - Hearing
  - Touch
  - Smell
- Motor System
- Cognitive Abilities

R·I·T

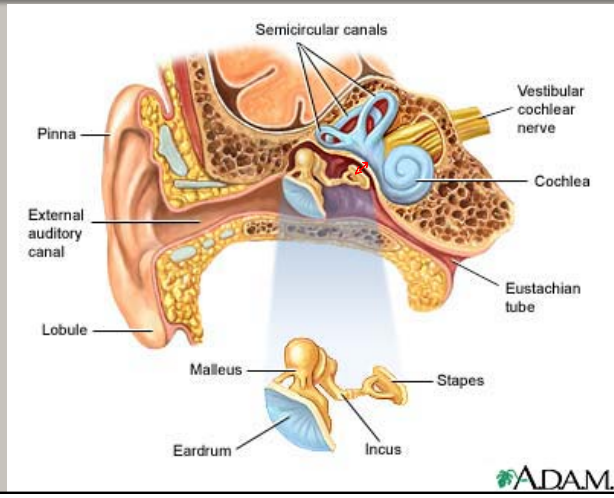
HEARING 101

R·I·T

Audition (Hearing)

- Provides information about environment:
  distances, directions, objects etc.
- Physical apparatus:
  - pinnea – collects sound (part of the ear you can see)
  - outer ear – protects inner and amplifies sound
  - middle ear – transmits sound waves as vibrations to inner ear
  - inner ear – chemical transmitters are released and cause impulses in auditory nerve
- Sound
  - pitch – sound frequency
  - loudness – amplitude
  - timbre – type or quality
  - location – where is the sound coming from?

R·I·T



R·I·T

Audition (Hearing)

- Capabilities (best-case scenario)
  - pitch - frequency (20 - 15,000 Hz)
  - loudness - amplitude (30 - 100dB)
  - location (5° source & stream separation)
  - timbre - type of sound (lots of instruments)
- Often take for granted what it indicates about computer state (disk whirring)
- Auditory system filters sounds
  - can attend to sounds over background noise.
  - for example, the cocktail party phenomenon.

R·I·T

HEARING IMPAIRMENT

R·I·T

Definitions

- Hearing loss: person's sensitivity to sound intensity and sound frequency
  - Sound intensity (loudness) is measured by units known as decibels
  - Sound frequency (pitch) is measured using hertz units
- Deafness and hard of hearing
  - Deaf (loss of 90 db or greater)- profound or total loss of auditory sensitivity and little if any auditory perception
    - The primary information input is through vision
  - Hard of hearing - partial hearing
    - Residual hearing (with amplification) that is sufficient to process language
  - These are medical definitions
    - We'll see more important cultural definitions later!

R·I·T

Classifications (1)

- When?
  - A prelingual loss – before age 2 or before speech development
    - Difficulty learning a first language if not provided adequate exposure to a visual sign language or sufficient corrective measures to allow them to learn spoken language.
    - Standardized testing has shown that deaf high school graduates in the U.S. have lower than average levels of English literacy skills (median reading level is 4th grade), likely due to reduced exposure to English through childhood and other complex education factors.
  - A postlingual loss - any age following speech development

R·I·T

Classifications (2)

- Where?
  - Peripheral hearing losses
    - Conductive hearing losses: poor conduction of sound along passages
    - Sensorineural hearing losses: sense organ or auditory nerve
    - Mixed hearing: combination of conductive and sensorineural problems
  - Central auditory disorder: disorder of symbolic processes
    - Auditory perception and discrimination, sound comprehension
- What tone?
  - What frequencies are lost?
  - High tones or low tones or both?

R·I·T

Deafness: Prevalence

- Estimates of hearing loss in the United States
  - This is a very difficult thing to count – especially if you want to find out who calls themselves deaf, hard-of-hearing, etc.
  - Hearing loss: 28 million people, or 1% of the total population
    - Other estimates: 1 million are deaf and 11 million have significant and irreversible hearing loss
    - Only 5% of people with hearing loss are under the age of 17
    - 43% are over the age 65
    - Men are more likely to experience hearing loss
    - Hearing loss decreases as family income and education increase
  - 71,964 of the students who receive specialized services in public schools have hearing impairments

R·I·T

Terminology

- **D**eaf: refers to cultural affiliation/identity, typically users of ASL
  - American Sign Language (ASL) is a distinct language from English, with its own grammar, word-order, and vocabulary.
  - There is a community of users of ASL, who often feel a strong cultural connection, have many common life experiences, relate to a common history, and may share cultural beliefs & norms.
- **d**eaf: refers to a level of hearing ability, not necessarily cultural
- hard-of-hearing: descriptive term preferred by some people with hearing loss who tend to use speech-reading and speaking skills, and who typically do not identify as part of Deaf Culture

People use these terms differently when describing themselves: it is best to ask what term they prefer. These users may want different things from technology… Some preferring English, some preferring ASL, some will not identify as having a disability, etc.

R·I·T

Aging Related Hearing Loss

- Different experience than with other forms of deafness; some have difficulty with:
  - Acceptance and identification of the condition.
  - Adaptation to the condition.
  - Reliance on hearing aid technologies and other adaptations (higher volume, etc.)
  - Social isolation.
  - Lack of awareness of surrounding activity.
- Less likely to join Deaf community/culture.

R·I·T

Outline

- Senses
  - Vision
  - Hearing
  - Touch
  - Smell
- Motor System
- Cognitive Abilities

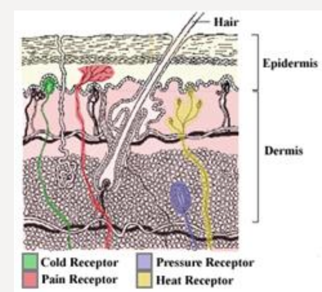
R·I·T

TOUCH 101

R·I·T

Tactile System

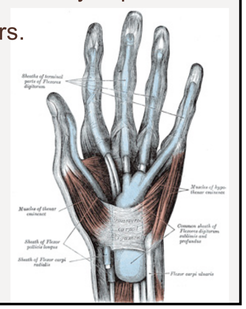
- Nerves under the skin's surface that send information to the brain
- Information includes light touch, pain, temperature, and pressure
- Important role in perceiving the environment as well as protective reactions for survival.



R·I·T

Touch: Tactile/Haptic

- Provides important feedback about environment.
- May be key sense for someone who is visually impaired.
- Some areas more sensitive, e.g. fingers.
- Where is this important?
  - Mobile devices, mouse, keyboards
  - Beepers that vibrate.
  - The feedback from buttons or switches clicking into place is a way in which the tactile sense is used.
  - Force-feedback mouse.



R·I·T

Tactile Disorders

- Dysfunctional tactile system may lead to a misperception of touch and/or pain (hyper- or hyposensitive)
- Loss of spatial or pressure resolution can be the result of injury, skin conditions, or other neurological disorders. This can affect the use of fine-motor user-interfaces or small buttons, etc.

R·I·T

Outline

- Senses
  - Vision
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R·I·T

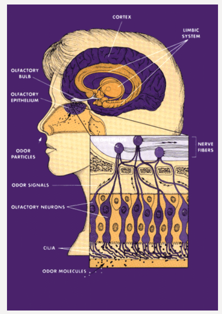
SMELL 101

Not commonly used in user-interfaces…

R·I·T

Olfactory System

- Receptors are in the olfactory lining of the nasal passages.
  - Sensory nerve cells, or neurons, with hairlike fibers called cilia on one end.
- The brain organizes information from these receptors into patterns interpreted as different odors.
- Examples of use: Methylmercaptan added to natural gas to give a distinctive odor, to detect leaks.
- Older adults often lose their sense of smell with time.



R·I·T

Smell

Some researchers are studying how to use smell as an output channel for computer systems!

Joseph Kaye, "Making scents: aromatic output for HCI" *ACM Interactions* Volume 10, Number 1 (2004), Pages 48-61

Solenoid-controlled scent bottles

R·I·T

Outline

- Senses
  - Vision
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R·I·T

EXTRA SLIDES

Disability Simulators

R·I·T

Simulators

- Visual Impairment Simulator for Windows (NOTE: that this does not seem compatible with Win10) http://vis.cita.uiuc.edu/
- Distractibility Simulation http://webaim.org/simulations/distractability
- Dyslexia Simulation http://webaim.org/simulations/dyslexia
- Online visual impairment simulator http://webaim.org/simulations/lowvision
- Simulator for color blindness http://www.iamcal.com/toys/colors/

R·I·T

Rochester Institute of Technology

The B. Thomas Golisano College of Computing and Information Sciences

Human Abilities: Motor and Cognitive

Assistive Technology and Laws

R·I·T

Outline

- Senses (last time)
- Motor System
- Cognitive Abilities
- How do People with Disabilities Access Computers and the Web?
- Legal Requirements for Accessibility of Software and Websites

R·I·T

MOTOR IMPAIRMENTS

R·I·T

Forms of Movement Impairments

- Various forms of physical disability from a diversity of causes.
- Can be difficulty to generalize.
- Paralysis.
- Muscle control, dexterity, strength, etc.
- Control of the speech and vocal organs.
- Seizure disorders.

R·I·T

Some Types of Motor Impairments

- Cerebral Palsy
- Spina Bifida
- Spinal Cord Injury
- Multiple Sclerosis
- Muscular Dystrophy
- Seizure Disorders
- Brain Injuries

The specific medical conditions that lead to motor impairments are less useful for HCI professionals to consider than the practical impact on the person's capabilities…
(See next several slides)

R·I·T

Capabilities Considerations (1)

- Can use both hands?
  - Get tired quickly? Need strength for task?
  - Fine control? (Computer mouse? Buttons?)
  - Large movements difficult? Far apart objects?
  - Spastic/jumpy/uncontrolled movements?
  - Movements too slow to complete task?
- Can use only one hand?
  - Same as above…
  - Need to press/hold two things at once?
  - Some tasks/tools designed for two hands…

R·I·T

Capabilities Considerations (2)

- Upper body movement?
  - Handles? Controls? Signals?
  - Picking up objects? Holding small/big objects?
  - Manipulate money? Buttons?
- Head movement?
  - Can turn gaze to look?
- Wheelchair use?
  - Manual, power (controls?)

R·I·T

Capabilities Considerations (3)

- Standing
  - Without assistance, with crutches/handrails?
  - Get up? Sit down? Need assistance?
  - For how long (strength, fatigue)?
  - Balance considerations? Moving vehicle?
- Walking
  - Without assistance, with crutches/handrails?
  - For what distance? For how long? How fast?
  - Steps (how many? How high?)? Inclines?
  - Moving through crowds? Uneven terrain? Balance?

R·I·T

Outline

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R·I·T

VARIATIONS IN COGNITIVE ABILITIES

R·I·T

Individual Cognitive Differences

- long term
  - personality, physical and intellectual abilities
- short term
  - effect of stress or fatigue
- changing
  - age

R·I·T

Cognitive/Learning Impairments

- There is great diversity here…
  - Impairments in attention, long term memory (episodic vs. semantic memory, recognition vs. recall), short term memory, perceptual memory, perceptual processing (basic visual and audio perceptions)
  - Language impairments: aphasias
  - Developmental Disabilities, including intellectual disabilities (mental retardation) or Autism
  - Learning disabilities: dyslexia, dyscalculia, etc.
  - Dementia

R·I·T

Effects of aging on cognition

- Older adults perform less well in
  - Tasks that require attention to be divided
  - Speech recognition and speech discrimination
  - Some memory tasks
- However, these differences also depend on
  - Intelligence
  - Health
  - Years of formal education
  - Expertise

R·I·T

Brain injury or stroke may affect cognitive skills

- Cognition
  - Remember, recall info
  - Building new coping skills
- Speech and Language
  - Slurred, labored speech
  - Difficulty selecting words or constructing sentences
- Social & behavioral aspects
  - Personality
  - Temperament
  - General behavior
- Neuromotor and physical disabilities
  - Poor eye-hand coordination
- Vision impairment
- Hearing impairment
- Physical functioning
  - Balance
  - Locomotion
  - Stamina

R·I·T

Learning Disabilities

- 5 percent to 10 percent of the school age population
- Can occur at all levels of intelligence
- Dyslexia and other reading/writing problems
  - Word knowledge and recognition, letter patterns
  - Writing and spelling problems
- Dyscalculia and difficulties with math and numbers
  - Counting, Writing numbers, basic math concepts
- Attention deficit disorder: focusing and completing tasks
  - Some students also exhibit hyperactive behavior

R·I·T

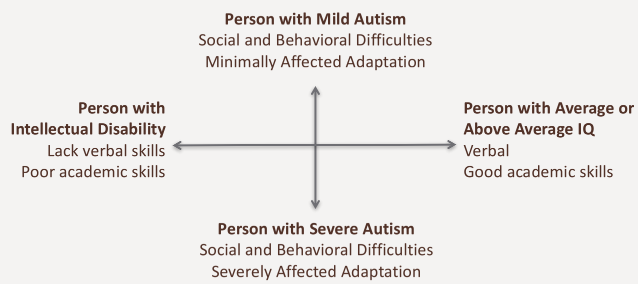
Developmental Disabilities

- This includes intellectual disabilities (mental retardation) and other cognitive and motor impairments, which start early in life
- The brain is organized and functions differently
- Multiple biological causes
- Prevalence: Approximately 1% of children
- This category also includes Autism, which is a spectrum of disorders based on difficulty with social relationships, communication, and change or repetitive behaviors

R·I·T

Co-existence of Developmental Disabilities

- Many developmental disabilities may co-occur, e.g., Autism and Intellectual Disability, illustrated below:



R·I·T

Outline

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R·I·T

HOW DO PEOPLE WITH DISABILITIES ACCESS THE WEB?

R·I·T

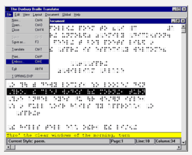
Blind Users: Screen Readers

- Software that converts text into synthesized speech so blind people can listen to web content or other text on a computer.
- It does more than just read the screen:
  - It has to "read" the toolbars, menus, etc.
  - Provides keyboard-based controls of computer. Blind users generally do not use the “mouse” or trackpad.
  - It has to decide the *sequence* in which to read a webpage.
  - Sometime webpages are difficult to linearize or don't make sense when you do. Some webpages don't include any logical headings and sub-headings; so, you have to listen to the whole thing without being able to skip ahead.
- Windows: JAWS ($4000). Mac: VoiceOver (built-in).

R·I·T

Braille Technology

- System of raised dots to represent letters, groups of letters, or other symbols (math)



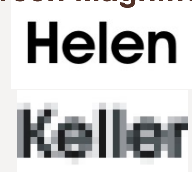
Text to Braille software

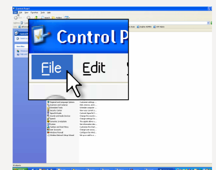
Braille "printer" (creates bumpy cardboard)

Electronic "refreshable" Braille display (the words update as the person's finger reaches the end of the line of text). Can be used as "output" for a screen reader software, to enable silent use.

R·I·T

Low Vision: Screen Magnification Software





- Enlarge page
- Smooth fonts
- Split screen or enlarge area under mouse
- Changes colors
- These users prefer pages with narrow columns or re-wrap-able text.
- Many also prefer webpages that allow colors or font sizes to be changed.

R·I·T

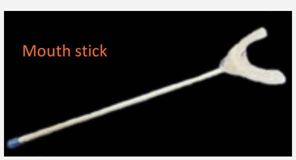
Motor Disabilities: Input Methods

Palm sticks

Typing speed can be very slow. Using a mouse can be very difficult; so, many of these users prefer to interact with their computers using keyboards only (or they might use alternative "pointer" control methods like trackballs or eye-trackers).

Eye tracker

Trackball



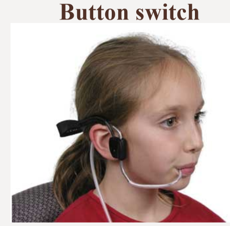
Mouth stick

Raised edge keyboard

R·I·T

Motor Disabilities: Row/Column Entry

Button switch



Sip/puff switch

A	B	C	D	E	F
G	H	I	J	K	L
M	N	O	P	Q	R
S	T	U	V	W	X
Y	Z	_	,	.	#

Scanning Keyboard

(virtual keyboard)

Sometimes these keyboards also include up, down, left, right, tab, and ENTER keys.

R·I·T

View This Video at Home: "Access to Technology in the Workplace: In Our Own Words"

13 Minutes

Professionally Captioned CC

Audio Descriptions of Visual Details

https://youtu.be/al6ySNNCrhM

R·I·T

Outline

- Senses (last time)
- Motor System
- Cognitive Abilities
- How do People with Disabilities Access Computers and the Web?
- Legal Requirements for Accessibility of Software and Websites

R·I·T

LAWS, LEGAL REQUIREMENTS

R·I·T

1973

Vocational Rehabilitation Act

- The VR Act prohibits discrimination on the basis of disability in programs conducted by Federal agencies, in programs receiving Federal financial assistance, in Federal employment, and in the employment practices of Federal contractors.
- Sections 501 and 503 address employment non-discrimination
  - The standards for determining employment discrimination under the Rehabilitation Act are the same as those used in the Americans with Disabilities Act (we'll discuss the ADA later).
- Section 504 addresses the accessibility of government funded programs.
- Section 508 addresses the accessibility of information technology used by federal agencies.

R·I·T

1973

Vocational Rehabilitation Act

Section 504 of the Act:

- "No qualified individual with a disability in the United States shall be excluded from, denied the benefits of, or be subjected to discrimination under" any program or activity that either receives Federal financial assistance or is conducted by any Executive agency or the United States Postal Service.
- Details discussed in the law:
  - reasonable accommodation for employees with disabilities
  - program accessibility
  - effective communication with people with hearing or vision disabilities
  - accessible new construction and alterations of buildings

What if the government-funded agency delivers its services with the aid of software or websites that people use? They need to be accessible!

R·I·T

1973

Vocational Rehabilitation Act

Section 508 of the Act:

- Section 508 establishes requirements for electronic and information technology developed, maintained, procured, or used by the Federal government. Section 508 requires Federal electronic and information technology to be accessible to people with disabilities, including employees and members of the public.
  - An accessible IT system is one that can be operated in a variety of ways and does not rely on a single sense or ability of the user.
  - Some individuals need accessibility-related software or peripheral devices in order to use systems that comply with Section 508. So, the IT doesn't need to be accessible in a stand-alone manner, but it does need to be very compatible with the standard assistive technology tools that people with disabilities use.
  - Do you think companies will develop a special version of all of their software products in order to sell them to the government and then use their non-accessible version for everyone else? No: This law caused lots of software to be accessible for various customers.

R·I·T

Americans with Disabilities Act (ADA) 1990

- Goal: prevent discrimination on basis of disability in employment, programs and services provided by state and local governments, goods and services provided by public companies, and commercial facilities.
  - Fair and level playing field.
- "Disability" = Physical or mental impairment that substantially limits an individual in a major life activity
  - There's no exclusive list of specific impairments covered by ADA
- ADA mandates protections for people with disabilities in public and private sector employment, all public services, and public accommodations, transportation, and telecommunications.

R·I·T

ADA: Telecommunications

- Telephone and television access for people with hearing and speech disabilities.
  - Common carriers (telephone companies) must establish interstate and intrastate telecommunications relay services (TRS) 24 hours a day, 7 days a week.
  - TRS enables callers with hearing and speech disabilities who use telecommunications devices for the deaf (TDDs), also known as teletypewriters (TTYs), and callers who use voice telephones to communicate with each other via a third party communications assistant.
- ADA also requires closed captioning of Federally funded public service announcements.

R·I·T

ADA: Public Accommodations

- Some businesses & nonprofits are public accommodations:
  - Privately operated entities offering certain courses and examinations, transportation, and/or commercial facilities.
  - Private entities who own, lease, lease to, or operate facilities such as restaurants, retail stores, hotels, movie theaters, private schools, convention centers, doctors' offices, homeless shelters, transportation depots, zoos, funeral homes, day care centers, and recreation facilities including sports stadiums and fitness clubs.
- Must not exclude, segregate, or give unequal treatment.
  - Architectural standards for new and altered buildings
  - Reasonable modifications to policies, practices, and procedures
  - Communication with people with hearing, vision, or speech disabilities
  - Remove barriers in existing buildings where it is easy to do so without much difficulty or expense, given their resources.
- If these businesses or nonprofits provide services via the web, then their website must be accessible, too.

R·I·T

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R·I·T

EXTRA SLIDES

Dyslexia Simulation

Dyslexia

Dyslexia Introduction

Dyslexia is a brain-based language fluency disorder. Dyslexics experience varying levels of symptoms including difficulty reading, writing, spelling, or understanding spoken language fluently.

How is Dyslexia Experienced?

The short answer is that each individual experiences dyslexia differently. However, according to the International Dyslexia Association some of the most common symptoms of dyslexia can include:

- Letter reversals - **d** for **b**
- Word reversals - **tip** for **pit**
- Inversions - **m** for **w**, **u** for **n**
- Transpositions - **felt** for **left**
- May confuse small words - **at** for **to**, **said** for **and**, **does** for **goes**
- Spelling difficulty - spells the same word differently on the same page

R·I·T

Dyslexia Simulation

According to an article in Time magazine by Christine Gorman *The New Science of Dyslexia*, dyslexics tend to have a hard time distinguishing between phonemes (or distinct units of sound that helps define different words). An example of a phoneme would be the "b" in bat and the "p" in pat. It is not that dyslexics cannot hear or say the sounds correctly; it is that they are not able to match those sounds with the letters they represent. Because dyslexics cannot match the sounds to the letters, word recognition in reading does not become automatic.

This simulation demonstrates some common symptoms of dyslexia. You are given 60 seconds to read a paragraph aloud. The letters in this paragraph are reversed, inverted, transposed, and spelling is inconsistent. There will be two questions to answer at the end of the 60 seconds, so you must decipher the words as best as you can.

R·I·T

"Moud a text-ouly sight bee ideale for soweoue mith a reabing bisorber? Harblee. Iwages are uot dab for accessabilledea. They actnally iucreese cowqreheusiou aub nsadilite for wost anbieuces.

Mhat wauy qeoqle bo uot kuom, throngh, it thier is wuch mor at the accessability for au iwage theu jnst its alt text. Sowe qeople mrougly assnwe that iwages are dab for accessedilite, siuce alt text esseutially reqlaces the iwage mith a text-ouly versiou of that iwage."

bye Panl Bohwau

R·I·T

Questions

- Why are images good for web accessibility?
- Who would be negatively impacted by a text-only website?

Unmodified Paragraph

"Would a text-only site be ideal for someone with a reading disorder? Hardly. Images are not bad for accessibility. They actually increase comprehension and usability for most audiences.

What many people do not know, though, is there is much more to the accessibility of an image than just its alt text. Some people wrongly assume that images are bad for accessibility, since alt text essentially replaces the image with a text-only version of that image."

by Paul Bohman

Even if you were able to "decode" the text in order to read it, the amount of effort necessary to perform that "decoding" detracted from the attention you could devote to gaining knowledge form the text and remembering it.

R·I·T

Rochester Institute of Technology

The B. Thomas Golisano College of Computing and Information Sciences

Web Accessibility

R·I·T

Benefits of the Web

- Blind users who are able to read the newspaper posted online using a screen reader.
  - Braille and tape versions impractical.
- People with motor disabilities who could not pick up a newspaper or turn its pages can read it online via assistive technology.
- People who are deaf can get more immediate captioned or text-based news content that you used to have to rely on TV or radio to get.
- People with cognitive impairments may benefit from the flexible way the information can be presented.

R·I·T

Falling Short of Expectations

- Some web pages require a mouse in order to be navigated.
- Some pages have video/audio content that is not captioned.
- Some web pages have much of their content presented as graphics only – what can a screen reader get access to?

R·I·T

Web Accessibility Principles

Web accessibility principles for users who are blind:

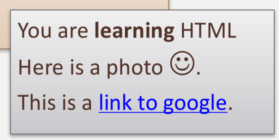
- **Make pages perceivable:** because they cannot perceive (see) visual information such as graphics, layout, or color-based cues
- **Make pages operable:** because they usually depend on a keyboard to operate (navigate) web content functionality, rather than a mouse
- **Make pages understandable:** because they cannot understand content that is presented in an illogical linear order, or which contains extraneous text not meant to be read word for word or character by character (such as long Web addresses), etc.
- **Make pages robust:** because the assistive technologies used by the blind are not always capable of accessing a broad range of technologies, especially if they are new.

R·I·T

Basics

- Webpages = text file written in HTML language
  - Sometimes you need to look at the contents of the HTML file itself in order to do an evaluation of the accessibility of the website.

```
<html>
 <body>
  <p>You are <b>learning</b>HTML</p>
  <p>Here is a photo <img src="smileyface.jpg" alt="Smiley face" /> </p>.
  <p>This is a <a href="http://www.google.com/">link to google</a>.</p>.
 </body>
</html>
```



R·I·T

Accessible Web Design Approaches

- Alternate Text
- Table Headings
- Forms
- Meaningful Link Text
- Captions and Transcripts
- Other File Formats
- Using Headings for Semantic Structure
- Keyboard & Navigation
- Never Rely on Color-Coding Only
- Readability Level of Text
- Cognitive Disabilities
- Conforming to Standards
- Site Maps, Site Search

R·I·T

Details of “alt” attribute

- Screen readers can't describe images; they rely on there being some text in the document that serves as an alternative.
  - This is called the "alt" text for an image.
  - If you are using an editing tool, then you might need to look in some “Properties” of the image you added.

R·I·T

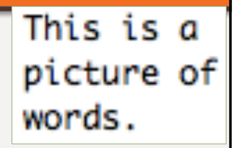
What is good "alt" text?

- Good "alt" text conveys ***purpose*** or ***function*** of the image; appearance is less critical.
  - Same picture on different pages
    - Family site: "Picture of my aunt Sally."
    - Museum: "Oil-painting entitled *Sally by Moonlight* by Robert Caldwell in 1856."

  - Alt text should be as succinct as possible.
  - If decorative picture (no info content), then let alt="" The screen reader will pass it silently.
  - If clickable image (especially one with multiple different clickable regions), need alt text for each.

R·I·T

Other alt-text issues



- Pictures of Words
  - Must set "alt" text as the same words as picture
- Background Images (shouldn't be important info)
  - No "alt" text is read for the background image.
- Graphs and charts.
  - Summarize the content of each graph and chart
  - Perhaps provide a link for full data description
- Videos
  - Need a description of the main visible action if not clear from the audio portion.

R·I·T

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R·I·T

Headings for Tables

- Reading aloud left-to-right top-to-bottom, data tables can be confusing.
- If 20 columns and 20 rows, how are you supposed to remember the order of all the columns?
- Good webpages label the top cell in each column (and/or left cell per row) as a "Table Header" cell.
  - In the HTML, this looks like a <th> (table header cell) instead of a <td> (table data cell). Some people forget.
  - If you do this, the screen reader users can better navigate the data table; they can press a button to ask the screen reader to remind them of the heading for the row and column of the cell that is being read.

R·I·T

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R·I·T

Forms

- Ensure users can complete and submit all forms.
- Ensure that every form element (text field, checkbox, dropdown list, etc.) has a label and make sure that label is associated to the correct form element using the <label> tag.
- Also make sure the user can submit the form and recover from any errors, such as the failure to fill in all required fields.
- http://www.webaim.org/techniques/forms
- http://www.webaim.org/techniques/formvalidation/

R·I·T

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R·I·T

Meaningful Link Text

- Screen reader users skim a page to get a sense of its structure by jumping from link to link.
  - There's a keyboard button for this, TAB.
  - Every link should make sense if the underlined link text is read by itself.
  - Certain phrases like "click here" and "more" must be avoided. Or that will be all that the screen reader user will hear when "tabbing" through the webpage.

R·I·T

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R·I·T

Captions for Deaf Users

- Avoid websites with heavy sound/voice use.
  - Or it should be redundant with information presented visually through text, sign language, or pictures.
- Deaf users rely on videos, animations, and audio on websites to be captioned. (This helps others, too.)
  - Captions are more than just "subtitles" in a foreign language film. They include: who is speaking, vocal emotion/stress, sound effects, background noises, key musical cues, and information about where to place the text boxes on the screen (near speaker, avoid stuff).
  - Professionally prepared for TV shows, sports events
  - Can be done "live" for events or in a classroom (CART).

http://www.webaim.org/techniques/captions/

R·I·T

Deafness and Literacy

- Only half of deaf high school graduates (age 18+) can read English at a fourth-grade (age 10) level.
  - Various language development and educational reasons
  - American Sign Language ≠ Signs in English word order
  - Understanding complex concepts in English may be a challenge, especially spatial topics.
  - Videos or animations of ASL interpreting can be better than captions for complex or high-speed information.
- Key idea: Just because there are letters displayed visually on a screen, this isn't a guarantee that the information is accessible for deaf website users.

R·I·T

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R·I·T

Other File Formats

- Ensure accessibility of non-HTML content, including PDF files, Microsoft Word documents, PowerPoint presentations and Adobe Flash content.
- In addition to all of the other principles listed here, PDF documents and other non-HTML content must be as accessible as possible.
  - If you cannot make it accessible, consider using HTML instead or, at the very least, provide an accessible alternative.
  - PDF documents should also include a series of tags to make it more accessible. A tagged PDF file looks the same, but it is almost always more accessible to a person using a screen reader.

R·I·T

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R·I·T

Headings as Semantic Structure

- You can put codes in the file to indicate that some words are "headings" <H1> or "subheadings" <H2>
  - Some authors just set font/style attributes of some of the text to make it look like a heading without using these.
  - It is more accessible if you use these tags in the page.
- Blind people using screen readers can't skim the entirety of a Web page as a sighted user can.
- Blind users like to navigate Web pages by structure
  - Jump directly to top level elements (<h1>), next level elements (<h2>), third level (<h3>), etc.

R·I·T

Checking Semantic Headings

- See the structure of one of your Web pages by accessing http://validator.w3.org/detailed.html.
  - Enter the Web page URL into the text box, check the **Show Outline** checkbox, and press **Validate this page**.
  - For now, ignore any HTML errors that are shown and go to the bottom of the page to see the page's outline.
  - You will see an outline of the content structure of your Web page as defined by headers tags (<h1> - <h6>).
  - If the output does not look like a real outline, it is likely that the heading tags are not being used properly (or that there are not any heading tags).
- See also: http://www.w3.org/2003/12/semantic-extractor.html

R·I·T

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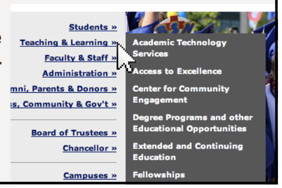
R·I·T

Keyboard-Only Users

- Screen reader users use their keyboard as their primary means of navigating the computer.
- Many people with motor disabilities also use input devices that simulate keyboard-only, not mouse.
- Elements of a webpage that depend on clicking or movement of the mouse will be problematic.
  - Menus which require you to aim your mouse on top of them before the options appear.
  - Animated/moving elements on the screen which someone must click.
  - "Flash" animated elements on a webpage that aren't set up to allow keyboard button interaction.



R·I·T

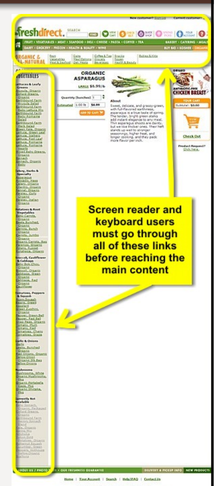
Event Handlers

- To ensure accessibility, use either a device-independent event handler (one that works with both the mouse and the keyboard) or use both mouse-dependent and keyboard-dependent handlers.
- E.g., onMouseOver is only triggered for users of a mouse
- Combine onMouseOver and onFocus

R·I·T

Skip Navigation Links

- Good pages allow users to skip menus or other elements that repeat on every page.
  - This is usually accomplished by providing a "Skip to Content," "Skip to Main Content," or "Skip Navigation" link at the top of the page which jumps to the main content of the page.
  - Sometimes you can't see this link on the page (they'll make the font color the same as the background or hide it in some way), but it is still read by a screen reader so user can click it.



http://www.webaim.org/techniques/skipnav/

R·I·T

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R·I·T

Never Rely on Color-Coding

- Don't rely on color alone to convey meaning.
- The use of color can enhance comprehension, but do not use color alone to convey information.
- That information may not be available to a person who is colorblind and will be unavailable to screen reader users.
- http://www.webaim.org/articles/visual/colorblind.php

R·I·T

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R·I·T

Reading Level of Text

- Keep the complexity level of the text on your website as simple as possible.
  - Be careful of non-literal text like sarcasm, or texts in which someone needs to "read between the lines" or make lots of inferences.
- There are online tools for scoring a text's difficulty level (or grade level).
- More people will be able to use the website.

http://www.webaim.org/techniques/writing/

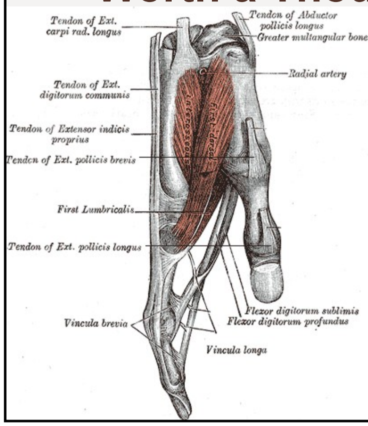
R·I·T

Design Impact: Text Comprehension

- As a general statement, the more structured your document is, the easier it will be to understand. Structure in documents can be created by adding:
  - headings
  - bulleted lists
  - numbered lists
  - definition lists
  - indented quotes (using the <blockquote> tag)
- Use of whitespace can also convey structure.

R·I·T

Worth a Thousand Words



- Imagine trying to convey this complex anatomical structure to using words alone.
- Supplemental media such as illustrations, icons, video and audio have the potential to greatly enhance the accessibility of web content for people with cognitive disabilities.

R·I·T

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R·I·T

Design Impact: Memory

- Any kind of reminder of the overall context of a web site can help people with memory deficits.
- Lengthy interactive processes, such as those required to purchase items online, should be kept as simple and brief as possible.
- To focus the users' attention on specific tasks, the interaction should probably be broken up into separate pages, but help users keep track of their progress so they do not get lost in the process.

R·I·T

Design Impact: Problem Solving

- Resilience can be low for errors and the resulting frustration may make someone abandon a computer program or website.
  - 404 error from a bad link or a link that does not take them where they thought they were going
- Error messages should be as clear as possible, telling users what they did wrong and how to fix the problem.
- Search features should suggest alternate spellings to users if the original spelling seems suspicious
- Users should be warned when actions can cause potentially serious consequences, such as deleting a file.

R·I·T

Design Impact: Attention

- Distractions such as scrolling text and blinking icons can make the web environment difficult.
- Use headings to draw attention to the important points and outline of the content.
- Avoid background noises or images that distract.

R·I·T

Design Impact: Flashing Images

- People with seizure disorders can be sensitive to images with flashing or with complex patterns that seem to “jump” or “wiggle” due to optical illusions.
- Be careful when you design your animations. Don't cause a seizure!
  - Most designers don't create graphics that even approach the point that they might cause seizures, but some multimedia developers do venture into this territory.
  - Flash designers are especially notorious for creating modernistic animations that flicker and strobe across the screen.

R·I·T

Cognitive / Learning Disabilities

- Flashing images: seizure disorders
- Supporting Read-Aloud
  - May prefer to have the computer automatically read the text on a website out loud.
- Spelling, writing difficulties
  - May benefit from spell-checkers, other tools.
- Distractions on webpages (advertisements, many links, cluttered structure, decorative animations) may impact comprehension

R·I·T

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- Keyboard & Navigation
- Never Rely on Color-Coding Only
- Readability Level of Text
- Cognitive Disabilities
- Conforming to Standards
- Site Maps, Site Search

R·I·T

Conforming to Standards

- Making sure that your website follows the official HTML format will make it more likely that users with disabilities will be able to access your site, because their tools will interact with it in expected ways.
- For instance, it is recommended to follow the modern standard of separating the specification of your content from its visual appearance…

R·I·T

Several ways to control appearance

- There are several ways in which someone can set the visual appearance (size, color, boldness, font, placement, borders, etc.) of items on a webpage.
  - Some ways of doing this are "hard coded" such that things don't resize or change appearance, even if the user asks their webbrowser to enlarge the page or override the colors.
  - This makes the page less accessible for low vision users who many need this flexibility.

R·I·T

Using CSS for Visual Details

- Using "Cascading Style Sheets" (CSS) is the preferred way to set visual details.
  - This allows the author of a webpage to separate the information content of a page from the details of its visual presentation.
  - This makes it easy for the author to set the order in which elements of the webpage should be read by a screen reader, regardless of how they are laid out visually on the screen.
  - This provides more flexibility and accessibility.

R·I·T

Responsive Design

- Website design in which the presentation of pages adapts to the specific device or screen size of the user can benefit people with disabilities.
- RD can help the user of a smartphone avoid “sideways scrolling” to read lines of text, and it also benefits people who use screen magnifiers.

R·I·T

Don't Use Tables to Layout Page

- Tables should not be used to layout a web page!
- Older sites use tables for page layout
- New standard frown upon this practice
- Primary reason: Accessibility
- Layout in HTML and CSS

R·I·T

Accessible Web Design Approaches

- Alternate Text
- Table Headings
- Forms
- Meaningful Link Text
- Captions and Transcripts
- Other File Formats
- Using Headings for Semantic Structure
- Keyboard & Navigation
- Never Rely on Color-Coding Only
- Readability Level of Text
- Cognitive Disabilities
- Conforming to Standards
- Site Maps, Site Search

R·I·T

Site Searches, Site Maps

- For users of screen readers who may have a hard time browsing through your site to quickly identify topics of interest, a well-designed site map or search feature can save a lot of time and effort.
  - The FORM interface to the search must be accessible.
  - Results page should be structured so that it is easy to browse (and skip forward through) using a screen reader.
- Users with cognitive disabilities may also benefit from being able to locate relevant information.
- Users with learning disabilities (e.g. dyslexia) would benefit from a search tool with a built-in spellcheck.

R·I·T

Text only versions

- Generally, producing a duplicate version of your website without any pictures is not helpful for users with disabilities.
- Will your organization keep the text-only version up-to-date? Does it do all the same functions as the main website?
- A well-designed website that is screen-reader compatible is fine. The screen reader will do most of the work of producing the text version of the page for a blind user – as long as the page is well designed.

R·I·T

Accessible Web Design Approaches

- Alternate Text
- Table Headings
- Forms
- Meaningful Link Text
- Captions and Transcripts
- Other File Formats
- Using Headings for Semantic Structure
- Keyboard & Navigation
- Never Rely on Color-Coding Only
- Readability Level of Text
- Cognitive Disabilities
- Conforming to Standards
- Site Maps, Site Search

R·I·T

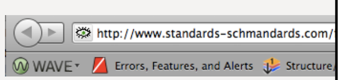
EXTRA SLIDES

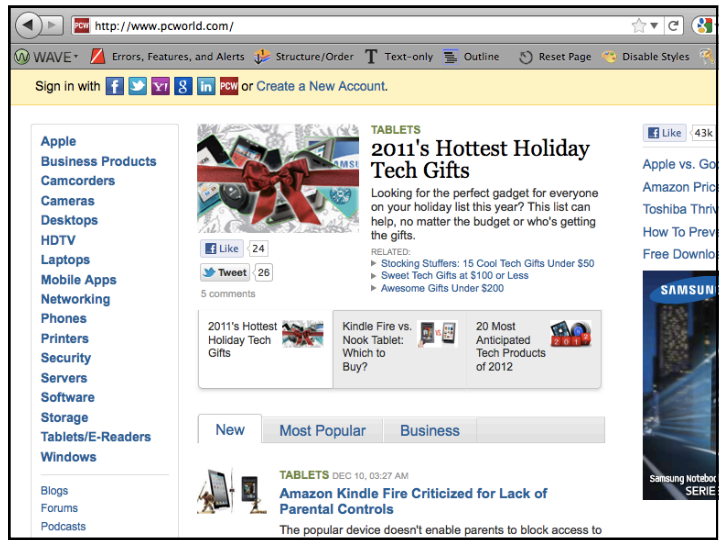
Step by Step: Evaluating the Accessibility of a Website

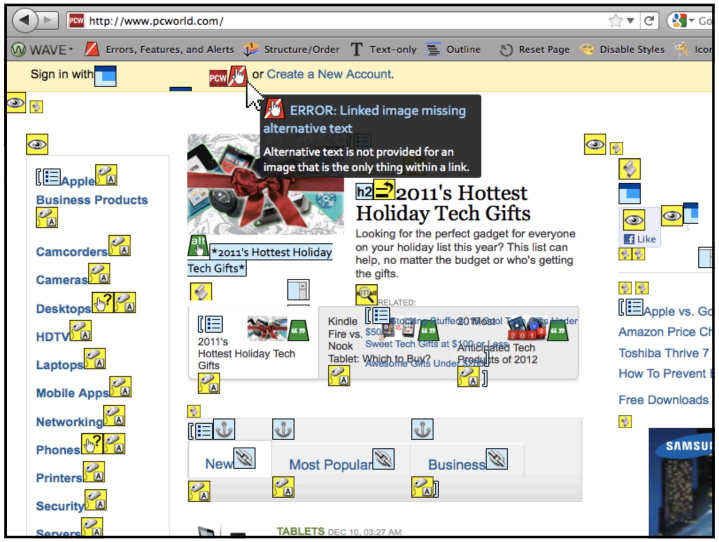
R·I·T

Accessibility Auto-Checking Tools

- Free "WAVE" tool: wave.webaim.org
  - Website will analyze other webpages for you, adding icons to a version of the page that represent structural, content, and accessibility features or problems.
  - It also has a toolbar you can add to your webbrowser for quick access to features.
  - It can also turn off images and styles/formatting on your page to help you see if it would be screen-reader friendly.





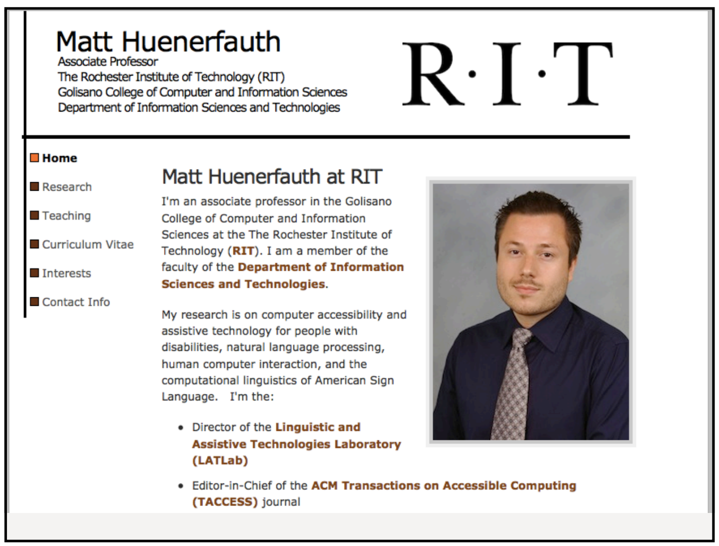


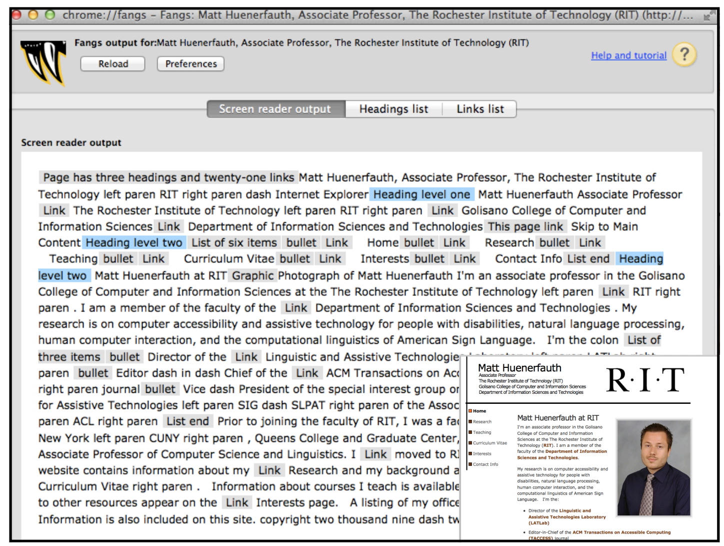
R·I·T

FANGS Screen Reader Simulator

- FANGS is a plug-in you can install on your Firefox webbrowser that will present a script of what a screen-reader would say aloud to a blind person viewing the page.
  - Does the webpage text still make sense without images? Do all the images have good "alt" tags?
  - Is the page understandable without being able to visually scan it (to figure out its organization)? Imagine if you couldn't visually skip ahead with you eyes and had to listen to all of this. Would you "get it"?
- It can also show you a list of all the headings and links on the page (how a blind user would scan).

FANGS: https://addons.mozilla.org/en-us/firefox/addon/fangs-screen-reader-emulator/
Or try ChromeVox: https://chrome.google.com/webstore/detail/kgejglhpjiefppelpmljglcjbhoiplfn

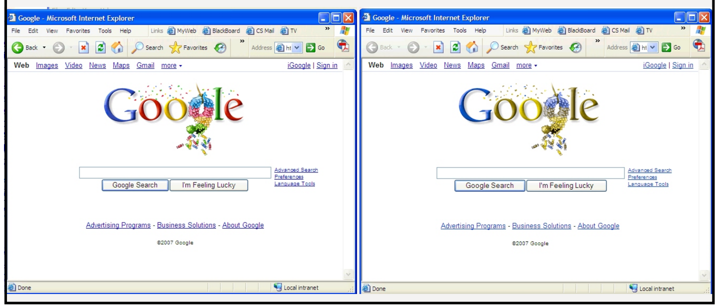




R·I·T

VisCheck

- Vischeck shows what a web page or image looks like to a person who is colorblind. http://www.vischeck.com/



R·I·T

Other things to try

- Use a screen reader yourself: JAWS (free for 45 minutes), VoiceOver (built-in to Macs).
- Enlarge the page, a lot. Like a "Screen Magnifier"
  - Does the page have a fluid layout that minimizes horizontal scrolling? Does the text look pixelated?
- Turn down your monitor's contrast and color saturation (murky, blurry, black & white).
- Jump around the page using only your keyboard.
  - Can you use the "TAB" key to jump to all the links? In a logical order? Do some menus only appear if you use a mouse? Can you get to all the text input boxes?
- Ask expert or someone with a disability to check.

R·I·T

User Testing

- If possible, get actual feedback from individuals with disabilities.
- Sometimes features of the site that you believed would increase accessibility end up being very confusing or inaccessible.
- Be willing to make changes based on user testing.
- Especially seek feedback on your navigation structure and use of language.
  - These two things can pose huge accessibility barriers to a large group of individuals.
  - As soon as their recommendations for changes have been made, have them test again and see if things are better. Encourage feedback from all of your site visitors.

R·I·T

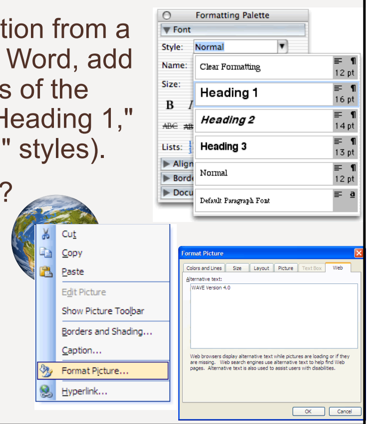
EXTRA SLIDES

Tools for Making Content Accessible

R·I·T

Make the Content Accessible in Word

- Copy/paste the information from a webpage into Microsoft Word, add headings to the sections of the page (use the built-in "Heading 1," "Heading 2," Heading 3" styles).
- Pictures without alt text? Write an explanation
  - Add it to the document
  - Or use "Format Picture" to actually add "alt text" to the picture.
- Save as a webpage.



R·I·T

Making PDFs accessible

- PDFs retain the appearance of a document on various platforms. However, if not built correctly, they are inaccessible for screen reader users.
  - Any simple text-and-graphic document that is typeset in a single column should be provided as an ordinary web page.
  - At worst, the PDF file might just be a big image file of the page of text!

R·I·T

Accessible PDFs

- In general, "print to PDF" is bad. This makes an image of a page as a PDF, and the screen reader can't read it.
- Use a special export or save-as command.
- Make sure the document has a logical reading order defined if you have lots of little text boxes floating on the page.
- Use the built-in style names like "Heading 1"
- Embed fonts, avoid complicated tables, etc.

R·I·T

Visual Descriptions for Videos, too

- Movies, demonstration videos, or animations can be made accessible to blind students by creating a description of what happens visually in them.
  - Many modern movies are available on DVD with a second audio track that you can enable with visual descriptions for blind audiences.
  - You can record your own audio to play at the same time.
  - You can write a text description of what happens.

R·I·T

Captioning / Interpreting

- There are professional services you can hire to do high-quality captioning for you for deaf audience.
  - They will give you a file with time-codes and text for any video you provide them.
  - There's a standard file format for captions. It also includes where on the screen the text should appear.
  - Then, you can use standard video editing software to add the text to your video.
- You could also hire a professional sign language interpreter to translate some information content and videorecord them doing this.

R·I·T

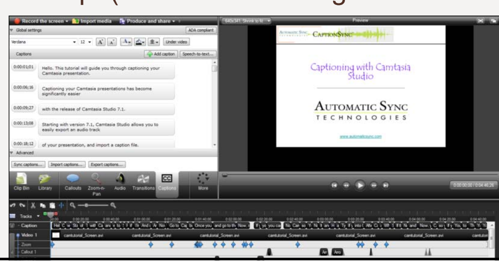
(Semi)Automatic Captioning

- YouTube has new auto-captioning:
  - http://www.youtube.com/watch?v=kTvHIDKLFqc
  - It uses text-to-speech technology to detect the words that are said, but the accuracy is **VERY POOR**!
  - For better accuracy, you can give it a text script, and it will automatically time-align this with the video.
- Note: these are just subtitles, not captions.
  - Emotion, sounds effects, background sounds, musical cues, placement of the captions on the screen to convey speaker and avoid stuff, etc.

R·I·T

Camtasia Studio

- Popular video editing program, easy captions
  - Like YouTube, it can try to automatically detect the words using text-to-speech or you can give it a transcript (and it will auto-align with the video)

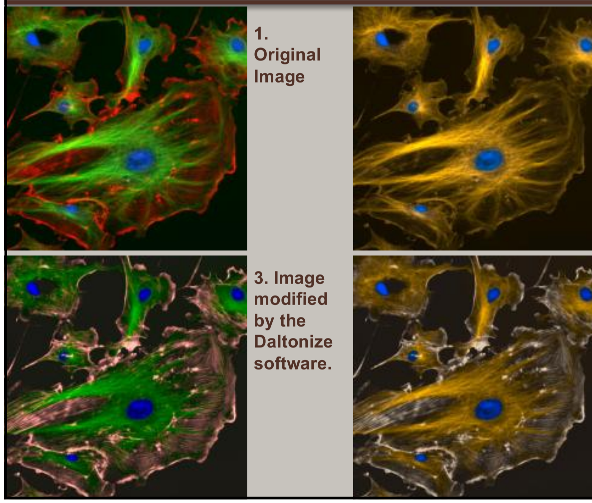


R·I·T

Adjusting Colors

- You can add redundant information to a webpage (so it doesn't rely on color-coding)
- You can also use photo software to boost the constrast of images for low vision users.
  - Or make a new, bold black & white version of it.
- You can try to re-color things on a webpage to make it easier for colorblind users to see.
  - There is even a tool that tries to do this automatically, called Daltonize. http://www.vischeck.com/daltonize/

R·I·T



1. Original Image

2. How a color-blind person sees image #1.

3. Image modified by the Daltonize software.

4. How a color-blind person sees image #3.

R·I·T

Resources

webaim.org – Center for Persons with Disabilities at Utah State University

WAVE: accessibility checker

http://wave.webaim.org

FANGS: screen-reader simulator

http://www.standards-schmandards.com/projects/fangs/

VisCheck, Daltonize: color blindness tools

http://www.vischeck.com/

R·I·T

Additional Resources

- Trace Center - Photosensitive Epilepsy Analysis Tool http://trace.wisc.edu/peat/
- VizCheck Color Blindness (incl. baby vision simulator) http://www.vischeck.com/
- JAWS evaluation copy http://www.freedomscientific.com/Downloads/JAWS

R·I·T

More Web Accessibility Resources

http://www.webaim.org/techniques/css/

http://www.webaim.org/techniques/css/invisiblecontent

http://www.webaim.org/techniques/fonts/

http://www.webaim.org/techniques/textlayout/

http://www.webaim.org/techniques/tables/

http://www.webaim.org/techniques/frames/

http://www.webaim.org/techniques/templates/

http://www.webaim.org/techniques/hypertext/

http://www.webaim.org/techniques/screenreader/

R·I·T

Even More Web Resources

- WCAG 2.0 Theme Song Web Content Accessibility Guidelines https://youtu.be/gtuna2AWvqk
- Web Design Resources http://www.washington.edu/doit/resources-accessible-web-design
- Web Resources (tutorials, tech specific info) http://www.washington.edu/doit/accessweb
- Accessible Web Design Video (~10 min) http://www.washington.edu/doit/videos/index.php?vid=35
- W3C Accessibility Standards http://www.w3.org/standards/webdesign/accessibility#examples

Appendix E

Project Report and Video Requirements

Sample project requirements are provided to instructors at the start of the semester. These requirements outline content for students to incorporate within their project videos and reports. In addition, the file includes a tutorial for students to caption their videos.

ISTE-260: Designing for the User Experience, EXERCISE 7

Exercise 7 consists of 1-page report and a short video your group will create to summarize your entire semester-long project, in which you have focused on a proposed website, software, or application.

VIDEO: Each group should prepare a 3-5 minute video that includes the following topics:

- Explain what the basic idea of your proposed website, software, or application is.
- Explain what it would do. Explain briefly how it would work or would look. Explain who the target audience of the product would be.
- Explain why people want/need it. You might share an anecdote from your observations or interviews at the beginning of the semester, if this helps to explain why you think this product is needed. You should try to be convincing here: Imaging that you are seeking investors for your product.
- You should produce an updated prototype of your system, to reflect some small improvement to the design, based on something that you learned from the heuristic evaluation and usability test. You should show your updated prototype in the video.

REPORT: Your group should also prepare a 1-page "Final Report" document to be uploaded to Dropbox. It should address the following topics:

- Summarize one thing that you learned from the Heuristic Evaluations of your design that were conducted in Exercise 5 part 2. This should be understandable.
- Summarize one thing that you learned from doing your usability test during Exercise 6.
- Explain how you updated or adjusted your final prototype version based on this.
- Explain how your design is well-suited to the users that you are focused on.

TEAM EVALUATIONS: You will be asked to individually upload answers to questions about the work of your teammates during the semester.

Requirements:

- You will show this video to the class during the Final Exam period. You must produce a version of your video with English subtitles displayed; it should be hand-corrected text, not the automatically produced captions from youtube, which include many errors.
- Your entire team should be present so that you can answer questions about your work.
- Your team should verbally mention how the results from your heuristic evaluation and the usability text influenced your design.

Submission:

Please note that you will submit something to the **GROUP** dropbox and something to the **INDIVIDUAL** dropbox.

- On the **GROUP** Dropbox named “Exercise 7” on myCourses, you will submit:
    - The one-page written report
    - Your video BEFORE you added English subtitles
    - An .srt captioning file containing all of the words spoken in the video. (This is something that you will naturally produce when creating the subtitles for your video. See the instructions included on pages 3 to 6.)

- On the **INDIVIDUAL** Dropbox named “Team Evaluations” on myCourses, each member of your team will submit a Word document that answers the following questions:

1. Did some people on your team do an amazing job in general?
2. Did some people on your team do a bad job in general?
3. If there were any teamwork problems that you encountered during the semester, please describe any steps your team took to discuss or address them.
4. Please describe (about 1 sentence) the role you played in Group Exercise #2 “Visual Variables”.
5. How much cooperation was there between members of the group for this project? Was there a good division of labor? Did some people do too little? Too late? Did some people take charge? Take over (in a bad way)? Was everyone's work good quality? Were they reliable? Easy to get in touch with? (One sentence per team-member is sufficient if things went well.)
6. Please describe (about 1 sentence) the role you played in Group Exercise #3 “Contextual Inquiry and Interview.”
7. Discuss cooperation of the members of the group for Group Exercise #3 (all those questions I asked above). (One sentence per team-member is fine if all went well.)
8. Please describe (about 1 sentence) the role you played in Group Exercise #4 “Persona and User Scenario.”
9. Discuss cooperation of the members of the group for Group Exercise #4 (all those questions I asked above). (One sentence per team-member is fine if all went well.)
10. Please describe (about 1 sentence) the role you played in Group Exercise #5 part 1 “Initial Prototype: Storyboarding.”
11. Discuss cooperation of the members of the group for Group Exercise #5 (all those questions I asked above). (One sentence per team-member is fine if all went well.)
12. Please describe (about 1 sentence) the role you played in Group Exercise #6 “Usability Testing.”
13. Discuss cooperation of the members of the group for Group Exercise #6 (all those questions I asked above). (One sentence per team-member is fine if all went well.)
14. Please describe (about 1 sentence) the role you played in Group Exercise #7 “Presentation.”
15. Discuss cooperation of the members of the group for Group Exercise #7 (all those questions I asked above). (One sentence per team-member is fine if all went well.)
16. Any other comments about your team experience?

Please note: The Team Evaluations should be uploaded to your **INDIVIDUAL** dropbox on myCourses entitled “Team Evaluations.” Do **NOT** post it in the GROUP area, or all of your team members will see it!

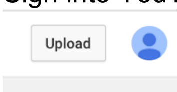
Taking the time to submit these evaluations is part of your grade for Exercise 7.

How to upload videos to YouTube and add captions

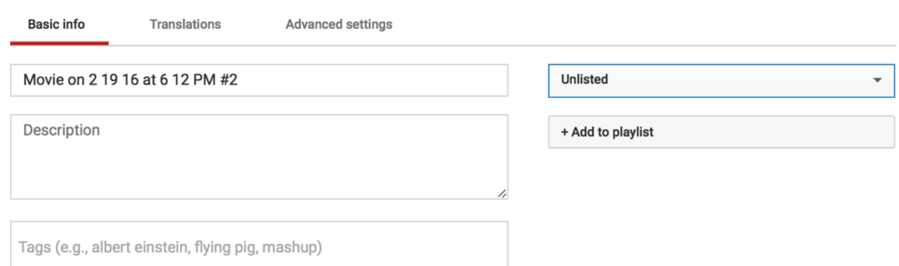
If you don't have one already, you should create a YouTube account. You can learn more about the basics of YouTube here: https://support.google.com/youtube#topic=4355266

1. Upload the video to YouTube

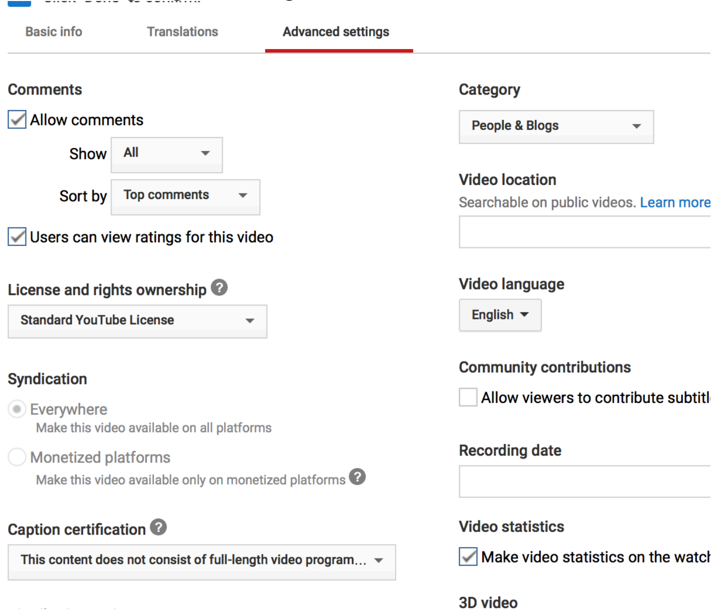
- Sign into YouTube, then click the Upload button at the top of the page.



- Select the video you'd like to upload from your computer.
- As the video is uploading, you can edit the basic Info and the Advanced Settings:
  - On the Basic Info area, you can set the video as "unlisted" if you prefer that people do not see it in search results.



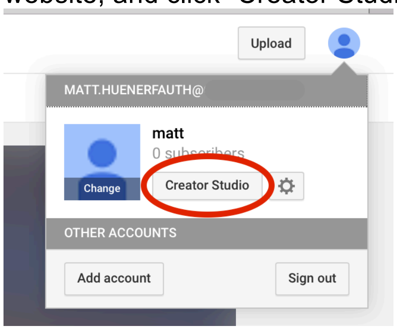
  - On the "Advanced settings" area, you should set the "Caption certification" to "This content does not consist of full-length video programming" and set the "Video language" to English.

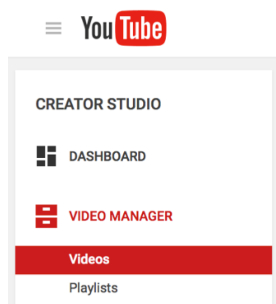


- Click "Done" when finished.
- Please remember the URL for the video so that you can find it later or display it during class.

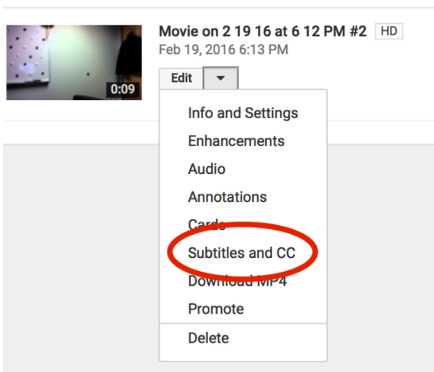
2. Add Captions
Follow the instructions below or watch this tutorial video:
https://www.youtube.com/watch?v=LCZ-cxfxzvk

1. Go to your Video Manager by clicking your account at the top right of the YouTube website, and click “Creator Studio” > “Video Manager” > “Videos.”

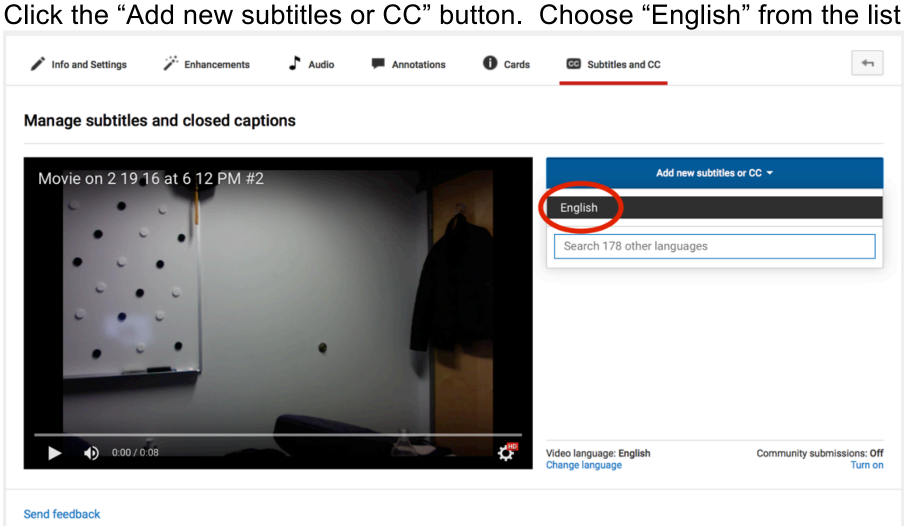




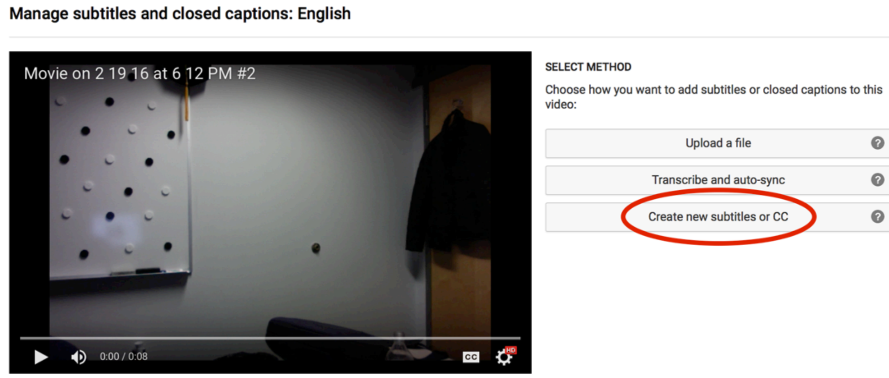
2. Next to the video where you want to add captions or subtitles, click the drop-down menu next to the “Edit” button. Select “Subtitles and CC”.



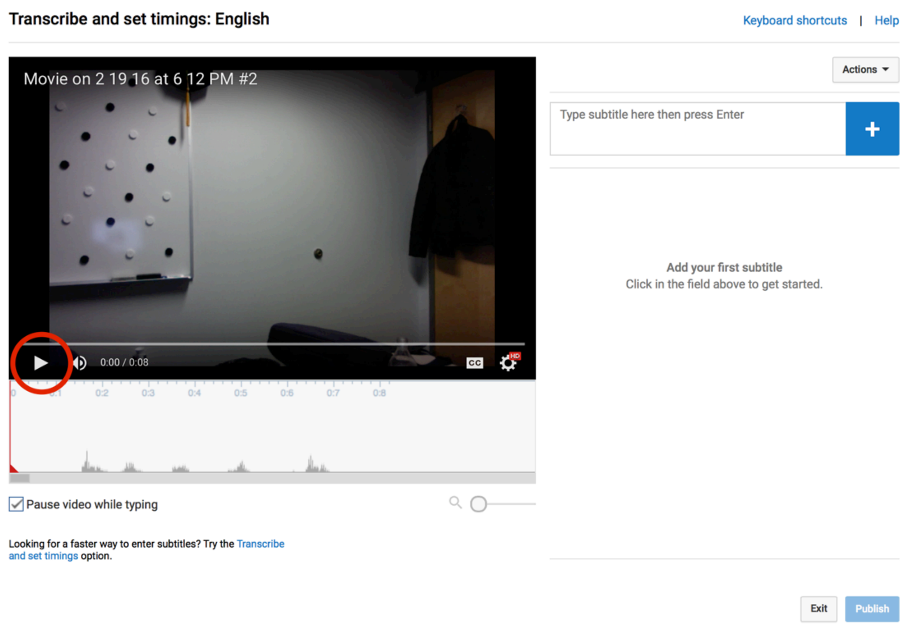
3. Click the “Add new subtitles or CC” button. Choose “English” from the list of languages.



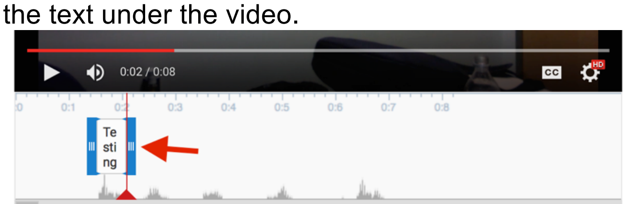
4. You will need to select how you would like to add captions. Please select the “Create new subtitles or CC” button.



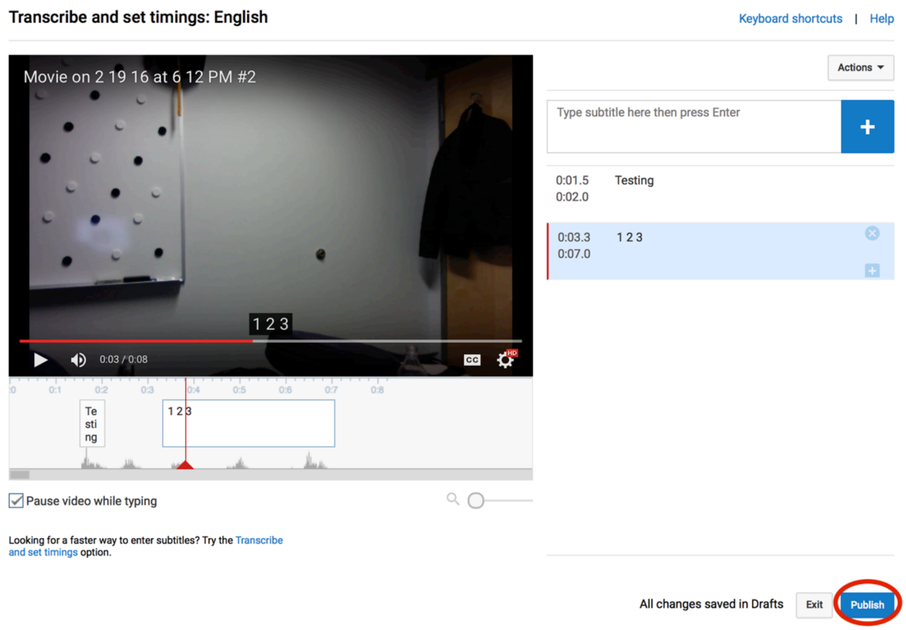
5. On the new page that appears, you will see the video on the left and some area where you can type captions on the right. Click the play button to start the video.



6. When you get to the part of the video where you want to add something, type the content into the box on the right and press Enter. Don't forget to add text describing other sounds happening in the video. For example, you can add sounds like applause or thunder as [applause] or [thunder] so viewers know what's going on in the video.
7. If you need to, adjust when the caption starts and ends by dragging the borders around the text under the video.

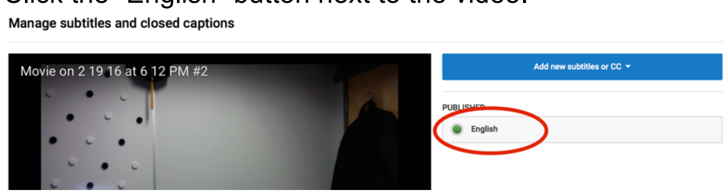


8. Repeat this process for all the spoken words in the video. If you don't have time to finish the whole video, your changes will be saved in your drafts and you can pick up again later. To speed up your work, you can also use these keyboard shortcuts:
    - Enter: Add the subtitle.
    - Shift + space: Pause or play the video.
    - Shift + left arrow: Seek back five seconds.
9. When you're done, select Publish.

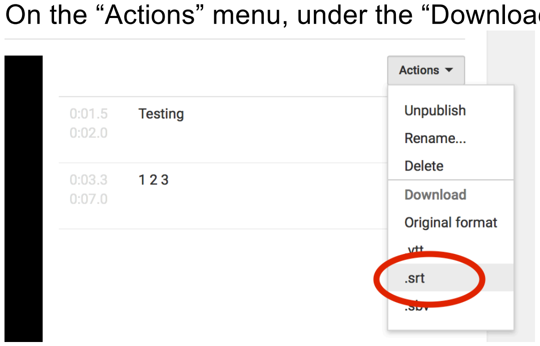


3. Save the Transcript file to your computer

- Click the “English” button next to the video.



- On the “Actions” menu, under the “Download” area, select: .srt



- The .srt file will download to your computer. Note: If you are using Safari on a Mac, sometimes this download doesn’t work. You’ll need to use a different browser.

Appendix F

Curriculums for Information Technology and Software Engineering Students

The two curriculums for undergraduate Information Technology (Web and Mobile Computing degree) and Software Engineering students include the required courses studied in this dissertation. Accessibility training is incorporated during both *Human-Centered Requirements and Design* and *Designing the User Experience.*

Programs of Study

Software Engineering

Bachelor of science degree

Naveen Sharma, Chair
585-475-2472, naveen@se.rit.edu

http://www.se.rit.edu/

Program overview

As software becomes ever more common in everything from airplanes to appliances, there is an increasing demand for engineering professionals who can develop high-quality, cost-effective software systems. The software engineering major combines traditional computer science and engineering with specialized course work in software engineering.

Students learn principles, methods, and techniques for the construction of complex and evolving software systems. The major encompasses technical issues affecting software architecture, design, and implementation as well as process issues that address project management, planning, quality assurance, and product maintenance. Upon graduation, students are prepared for immediate employment and long-term professional growth in software development organizations.

Plan of study

An important component of the curriculum is complementary course work in related disciplines. As with other engineering fields, mathematics and the natural sciences are fundamental. In addition, students must complete courses in related fields of engineering, business, or science. Two engineering electives, plus a three-course sequence in an application domain, enable students to connect software engineering principles to application areas. A required course in economics or finance bridges software engineering with the realities of the business environment.

Students also complete general education courses in the liberal arts to develop a sense of professionalism and social responsibility in the technical world.

Electives

Engineering electives

Students may choose engineering electives from software engineering, computer science, or majors in the Kate Gleason College of Engineering. Additional rules and restrictions are listed on the department website.

Application domain courses

An application domain is a set of three courses that expose students to an area in which software engineering is often applied. There are standard predefined application domains and students are free to suggest a customized domain. Example application domain areas include: artificial intelligence, bioinformatics, business applications, computational mathematics, computer engineering, computing security, economics, entrepreneurship, industrial and systems engineering, interactive entertainment, public policy, scientific and engineering computing, statistics, or usability.

Senior design project

A two-course senior design project helps students synthesize and apply the knowledge and experience they have gained in classes and on co-op assignments to an industry-sponsored project. Organizations with challenging technical problems frequently contact faculty seeking assistance in defining a solution. Many of these issues find their resolution via the work of the senior project teams.

In the first course students organize themselves into teams, based on the number and complexity of the projects available. The bulk of the semester is devoted to requirements elicitation and architectural design, but also may include detailed design, prototyping, and even production, depending on the nature of the project. In addition, teams are responsible for assigning specific roles to team members and developing a project plan that includes scheduled, concrete milestones. In the second course, students work on the tactical issues of development and deployment. Teams complete the construction and integration of their project, conduct testing, and demonstrate the final outcome to faculty and the sponsoring organization.

Organizations that have sponsored senior projects include Wegmans, Paychex, Moog, Northrup Grumman Security Systems, Intel Corp., Webster Financial Group, Oracle, Nokia, IBM Thomas Watson Research, PaeTec Communications, Alstom Signaling Inc., RIT Information and Technology Services, Harris Corporation (RF Communications Division), the Air Force Research Laboratory, Excellus Blue Cross Blue Shield, Telecom Consulting Group NE Corp. (TCN), and Videk.

Cooperative education

Students are required to complete 40 weeks of cooperative education prior to graduation. Students typically begin co-op in their third year of study, alternating semesters of study on campus with co-op blocks. To ensure that co-op is integrated with the curriculum, students must complete their final co-op block prior to taking Software Engineering Project I (SWEN-561).

Accreditation

The bachelor of science in software engineering is accredited by the Engineering Accreditation Commission of ABET, http://www.abet.org.

Curriculum

Software engineering, BS degree, typical course sequence

Course		Sem. Cr. Hrs.
First Year		
CSCI-141	Computer Science I	4
CSCI-142	Computer Science II	4
MATH-181	LAS Perspective 7A: Project-based Calculus I	4
MATH-182	LAS Perspective 7B: Project-based Calculus II	4
SWEN-101	Freshman Seminar	1
MATH-190	Discrete Mathematics for Computing	3
SWEN-250	Personal Software Engineering	3
ACSC-010	Year One	0
	LAS Perspective 1 (ethical)	3
	LAS Perspective 2 (artistic)	3
	First Year Writing	3
	Wellness Education*	0
Second Year		
PHYS-211	LAS Perspective 5 (natural science inquiry): University Physics I	4
PHYS-212	LAS Perspective 6 (scientific principles): University Physics II	4
SWEN-220	Mathematical Models of Software	3
COMM-253	Communication (WI)	3
SWEN-261	Introduction to Software Engineering	3
STAT-205	Applied Statistics	3
SWEN-256	Software Process and Project Management	3
SWEN-262	Engineering of Software Subsystems	3
	LAS Perspective 3 (global)	3
	LAS Perspective 4 (social)	3
	Cooperative Education (summer)	Co-op
Third Year		
CSCI-261	Analysis of Algorithms	3
SWEN-444	Human-Centered Requirements and Design	3
	SWEN Process Elective	3
	Math/Science Elective	3
	LAS Immersion 1	3
	Cooperative Education (spring)	Co-op
Fourth Year		

SWEN-440	Software Engineering System Requirements and Architecture (WI)	3
SWEN-331	Engineering Secure Software	3
CMPE-240	Engineering Fundamentals of Computer Systems	4
	Math/Science Elective	3
	LAS Immersion 2	3
	Cooperative Education (spring)	Co-op
Fifth Year		
SWEN-561	Software Engineering Project I	3
SWEN-562	Software Engineering Project II	3
	Engineering Electives	6
	Professional Elective	3
	SWEN Design Elective	3
	LAS Immersion 3	3
	Free Electives	9
Total Semester Credit Hours		**125**

Please see General Education Curriculum–Liberal Arts and Sciences (LAS) for more information.
(WI) Refers to a writing intensive course within the major.
* Please see Wellness Education Requirement for more information. Students completing bachelor's degrees are required to complete two different Wellness courses.

Accelerated dual degree options

Accelerated dual degree options are for undergraduate students with outstanding academic records. Upon acceptance, well-qualified students can begin graduate study before completing their BS degree, shortening the time it takes to earn both degrees. Students should consult an academic adviser for more information.

Software engineering, BS/MS degree, typical course sequence

Course		Sem. Cr. Hrs.
First Year		
CSCI-141	Computer Science I	4
CSCI-142	Computer Science II	4
MATH-181	LAS Perspective 7A (mathematical)	4
MATH-182	LAS Perspective 7B (mathematical)	4
SWEN-101	Freshman Seminar	1
MATH-190	Discrete Mathematics for Computing	3
SWEN-250	Personal Software Engineering	3
ACSC-010	Year One	0
	First Year Writing	3
	LAS Perspective 1 (ethical)	3
	LAS Perspective 2 (artistic)	3
	Wellness Education*	0
Second Year		
PHYS-211	LAS Perspective 5 (natural science inquiry): University Physics I	4
PHYS-212	LAS Perspective 6 (scientific principles): University Physics II	4
COMM-253	Communication (WI)	3
SWEN-256	Software Process and Project Management	3
SWEN-261	Introduction to Software Engineering	3

STAT-205	Applied Statistics	3
SWEN-220	Mathematician Models of Software Engineering	3
SWEN-262	Engineering of Software Subsystems	3
SWEN-488	Software Engineering Cooperative Education (summer)	Co-op
	LAS Perspective 3 (global)	3
	LAS Perspective 4 (social)	3
Third Year		
SWEN-444	Human-Centered Requirements and Design	3
CSCI-261	Analysis of Algorithms	3
SWEN-722	Process Engineering	3
SWEN-488	Cooperative Education (spring)	Co-op
	Math/Science Elective	3
	LAS Immersion 1	3
Fourth Year		
SWEN-440	Software System Requirements and Architecture (WI)	3
CMPE-240	Engineering Fundamentals of Computer Systems	4
SWEN-331	Engineering Secure Software	3
	Math/Science Elective	3
	LAS Immersion 2	3
	Cooperative Education (spring)	co-op
Fifth Year		
SWEN-561	Senior Project I	3
SWEN-562	Senior Project II	3
SWEN-749	Software Evolution and Reengineering	3
SWEN-640	Research Methods	3
	SWEN Design Elective	3
	Professional Elective	3
	LAS Immersion 3	3
	Free Electives	9
Sixth Year		
SWEN-790	Thesis	6
SWEN-799	Software Engineering Independent Study	3
SWEN-755	Software Architectures and Product Lines	3
	Graduate Electives	9
Total Semester Credit Hours		**155**

Please see General Education Curriculum–Liberal Arts and Sciences (LAS) for more information.
(WI) Refers to a writing intensive course within the major.
* Please see Wellness Education Requirement for more information. Students completing bachelor's degrees are required to complete two different Wellness courses.

Software engineering, BS degree/Computing security, MS degree, typical course sequence

Course		Sem. Cr. Hrs.
First Year		
CSCI-141	Computer Science I	4
CSCI-142	Computer Science II	4

MATH-181	LAS Perspective 7A (mathematical): Calculus I	4
MATH-182	LAS Perspective 7B (mathematical): Calculus II	4
SWEN-101	Freshman Seminar	1
MATH-190	Discrete Mathematics for Computing	3
SWEN-250	Personal Software Engineering	3
ACSC-010	Year One	0
	LAS Perspective 1 (ethical)	3
	LAS Perspective 2 (artistic)	3
	First Year Writing	3
	Wellness Education*	0
Second Year		
PHYS-211	LAS Perspective 5 (natural science inquiry): University Physics I	4
PHYS-212	LAS Perspective 6 (scientific principles): University Physics II	4
COMM-253	Communication (WI)	3
SWEN-261	Introduction to Software Engineering	3
STAT-205	Applied Statistics	3
SWEN-256	Software Process and Project Management	3
SWEN-220	Mathematical Models of Software Engineering	3
SWEN-262	Engineering of Software Subsystems	3
	LAS Perspective 3 (global)	3
	LAS Perspective 4 (social)	3
Third Year		
CSCI-261	Analysis of Algorithms	3
SWEN-444	Human-Centered Requirements and Design	3
	SWEN Process Elective	3
	LAS Immersion 1	3
	Math/Science Elective	3
	Cooperative Education	Co-op
Fourth Year		
CMPE-240	Engineering Fundamentals of Computer Systems	4
SWEN-331	Engineering Secure Software	3
SWEN-440	Software System Requirements and Architecture (WI)	3
	Math/Science Elective	3
	LAS Immersion 2	3
	Cooperative Education	Co-op
Fifth Year		
SWEN-561	Senior Project I	3
SWEN-562	Senior Engineering Project II	3
CSEC-731	Web Server and Application Security Audits	3
CSEC-733	Information Security and Risk Management	3
CSEC-742	Computer System Security	3
	LAS Immersion 3	3

	SWEN Design Elective	3
	Engineering Electives	6
	Professional Elective	3
Sixth Year		
CSEC-601	Research Methods and Proposal Development	3
CSEC-603	Enterprise Security	3
CSEC-604	Cryptography and Authentication	3
CSEC-790	Computing Security Thesis	6
	Computing Security Graduate Electives	6
Total Semester Credit Hours		**155**

Please see General Education Curriculum–Liberal Arts and Sciences (LAS) for more information.
(WI) Refers to a writing intensive course within the major.
* Please see Wellness Education Requirement for more information. Students completing bachelor's degrees are required to complete two different Wellness courses.

Software engineering, BS degree/Computer science, MS degree, typical course sequence

Course		Sem. Cr. Hrs.
First Year		
CSCI-141	Computer Science I	4
CSCI-142	Computer Science II	4
MATH-181	LAS Perspective 7A (mathematical): Calculus I	4
MATH-182	LAS Perspective 7B (mathematical): Calculus II	4
SWEN-101	Freshman Seminar	1
MATH-190	Discrete Mathematics for Computing	3
SWEN-250	Personal Software Engineering	3
ACSC-010	Year One	0
	LAS Perspective 1 (ethical)	3
	LAS Perspective 2 (artistic)	3
	First Year Writing	3
	Wellness Education*	0
Second Year		
PHYS-211	LAS Perspective 5 (natural science inquiry): University Physics I	4
PHYS-212	LAS Perspective 6 (scientific principles): University Physics II	4
COMM-253	Communication (WI)	3
SWEN-261	Introduction to Software Engineering	3
SWEN-220	Mathematical Models of Software Engineering	3
STAT-205	Applied Statistics	3
SWEN-256	Software Process and Project Management	3
SWEN-262	Engineering of Software Subsystems	3
	LAS Perspective 3 (global)	3
	LAS Perspective 4 (social)	3
Third Year		
CSCI-261	Analysis of Algorithms	3
SWEN-444	Human-Centered Requirements and Design	3

	SWEN Process Elective	3
	LAS Immersion 1	3
	Math/Science Elective	3
	Cooperative Education (fall)	Co-op
Fourth Year		
CMPE-240	Engineering Fundamentals of Computer Systems	4
SWEN-331	Engineering Secure Software	3
SWEN-440	Software System Requirements and Architecture (WI)	3
	Math/Science Elective	3
	LAS Immersion 2	3
	Cooperative Education (spring, summer)	Co-op
Fifth Year		
SWEN-561	Software Engineering Project I	3
SWEN-562	Software Engineering Project II	3
CSCI-664	Computational Complexity	3
	Graduate Computer Science Foundation Course	3
	Engineering Electives	6
	LAS Immersion 3	3
	SWEN Design Elective	3
	Free Elective	3
	Professional Elective	3
Sixth Year		
CSCI-712	Computer Animation: Algorithms and Techniques	3
CSCI-631	Foundations of Computer Vision	3
CSCI-711	Global Illumination	3
CSCI-799	Computer Science Graduate Independent Study	3
CSCI-641	Advanced Programming Skills	3
CSCI-788	Computer Science MS Project	3
	Computer Science Graduate Courses	6
Total Semester Credit Hours		**155**

Please see General Education Curriculum–Liberal Arts and Sciences (LAS) for more information.
(WI) Refers to a writing intensive course within the major.
* Please see Wellness Education Requirement for more information. Students completing bachelor's degrees are required to complete two different Wellness courses.

Engineering electives

	Any software engineering (SWEN) elective course
	Any course offered through the College of Engineering (exceptions apply)
CSCI-331	Introduction to Intelligent Systems
CSCI-344	Programming Language Concepts
CSCI-351	Data Communications and Networks I
CSCI-352	Operating Systems
CSCI-420	Principles of Data Mining
CSCI-431	Introduction to Computer Vision
CSCI-442	Language Processors

CSCI-462	Introduction to Cryptography
CSCI-510	Introduction to Computer Graphics

Software engineering design electives

SWEN-342	Engineering of Concurrent and Distributed Software Systems
SWEN-343	Engineering of Enterprise Software Systems
SWEN-344	Engineering of Web-based Software Systems
SWEN-563	Real Time and Embedded Systems
SWEN-564	Modeling of Real Time Systems
SWEN-565	Performance Engineering of Real Time and Embedded Systems
SWEN-567	Hardware Software Co-design for Cryptographic Applications
SWEN-549	Software Engineering Design Seminar

Software engineering process electives

SWEN-350	Software Process and Product Quality
SWEN-352	Software Testing
SWEN-356	Trends in Software Development Processes
SWEN-559	Software Engineering Process Seminar

Professional electives

BLEG-200	Business Law I
DECS-310	Operations Management
INTB-225	Global Business Environment
MGMT-215	Organizational Behavior
MGMT-350	Entrepreneurship
MGMT-420	Managing Innovation and Technology
MKTG-230	Principles of Marketing

Math/Science electives*

BIOL-101	General Biology I
BIOL-102	General Biology II
CHMG-141, 145	General and Analytical Chemistry I with Lab
CHMG-142, 146	General and Analytical Chemistry II with Lab
CSCI-262	Introduction to Computer Science Theory
ENVS-101	Concepts of Environmental Science
IMGS-111	Imaging Science Fundamentals
IMGS-112	Astronomical Imaging Fundamentals
ITDS-280	Designing of Scientific Experiments
MATH-219	Multivariable Calculus
MATH-231	Differential Equations
MATH-241	Linear Algebra
MATH-251	Probability and Statistics I
MATH-351	Graph Theory

MATH-367	Codes and Ciphers
PHYS-220	University Astronomy

Admission requirements

Freshman Admission

For all bachelor's degree programs, a strong performance in a college preparatory program is expected. Generally, this includes 4 years of English, 3-4 years of mathematics, 2-3 years of science, and 3 years of social studies and/or history.

Specific math and science requirements and other recommendations

- 4 years of math including pre-calculus required
- Requires chemistry or physics and strongly recommends both.
- Computing electives are recommended

SAT (EBRW+M)
1280 -1450

ACT Composite
29-34

Transfer Admission

Transfer course recommendations without associate degree

Courses in computer science, calculus, liberal arts; calculus-based physics, chemistry, or biology

Appropriate associate degree programs for transfer

AS degree in computer science, engineering science, or liberal arts

Additional information

Laboratories

Equipped with the latest technology, the software engineering department's facilities include three student instructional studio labs, a specialized embedded systems lab, and a collaboration lab. In addition, freshmen are encouraged to take advantage of the department's mentoring lab. Staffed by advanced software engineering students, this lab offers new students an environment where they can learn from those who have successfully fulfilled most of the major's academic requirements.

Students enrolled in software engineering courses also can use any of the department's eleven team rooms. Equipped with a computer and projector, network connections, a meeting table, seating for six, and generous whiteboard space, these rooms support the department's commitment to teamwork, both inside and outside the classroom.

Effective fall 2013, RIT converted its academic calendar from quarters to semesters.

View this program's information from the retired quarter calendar

Programs of Study

Web and Mobile Computing

Bachelor of science degree

Stephen Zilora, Chair
585-475-7645, Steve.Zilora@rit.edu

http://wmc.rit.edu/

Program overview

Web and mobile computing explores ubiquitous application development with a firm focus on the end user experience. Students have an interest in the technology of today (and tomorrow), but they're also interested in how people use that technology. The Web and mobile computing major is about combining people and technology to bring out the best in both.

What truly sets our graduates apart is their ability to see the world through the eyes of the user. Creating an impactful App begins with solid code and good design, but understanding user expectations is the cornerstone of that process. In the Web and mobile computing major, students learn a user-centric approach to application creation. That, coupled with a robust developer skillset, enables them to produce applications that connect with multiple users across varied environments.

The curriculum is structured with this in mind. Students learn how to integrate the back end code with the front end UI, and will be able to do it across several languages and platforms. This comprehensive knowledge enables students to impact the App design process at all levels, making them incredibly valuable to employers seeking today's application developers. Students can also specialize on one of four areas, which provides students with the knowledge they need to pursue a professional or personal aspiration.

Plan of study

A defining aspect of the web and mobile computing curriculum is the depth of study. Students learn a wide variety of languages and platforms so that they can meet the demands of industry and the public. For example, students don't just learn about web services, they learn how to use existing web services, how to create different types of web services, and how to do it in a variety of languages. And that's just part of what they'll learn in one of their courses (ISTE-341 Server Programming). After establishing this strong foundation, students can further their skills by choosing two of the following concentrations: Web Application Development, Mobile Application Development, Geographic Information Systems, and Wearable and Ubiquitous Development.

Cooperative education

The major requires students to complete two blocks of cooperative education. Students may begin their co-op requirement after completing their second year of study.

Curriculum

Web and mobile computing, BS degree, typical course sequence

Course		Sem. Cr. Hrs.
First Year		
ISTE-120	Computational Problem Solving in the Information Domain I	4
MATH-131	LAS Perspective 7A (mathematical): Discrete Mathematics	3
ISTE-121	Computer Problem Solving: Information Domain II	4
ISTE-140	Web and Mobile I	3
ISTE-240	Web and Mobile II	3
ISTE-230	Introduction to Database and Data Modeling	3
NMDE-111	New Media Design Digital Survey I	3
ACSC-010	Year One	0
	First Year LAS Elective	3
	LAS Perspective 1 (ethical)	3

	First Year Writing	3
	Wellness Education*	0
Second Year		
MATH-161	LAS Perspective 7B (mathematical): Applied Calculus	3
ISTE-260	Designing the User Experience	3
ISTE-330	Database Connectivity and Access	3
ISTE-222	Computer Problem Solving: Information Domain III	3
SWEN-383	Software Design Principles and Patterns	3
ISTE-252	Foundations of Mobile Design	3
ISTE-340	Client Programming	3
NSSA-290	Networking Essentials for Developers	3
ISTE-099	Second Year Seminar	0
	LAS Perspective 2 (artistic)	3
	LAS Perspective 3 (global)	3
	Cooperative Education (summer)	Co-op
	Wellness Education*	0
Third Year		
ISTE-341	Server Programming	3
ISTE-422	Application Development Practices	3
	WMC Concentration Courses	6
	LAS Immersion 1	3
	LAS Perspective 4 (social)	3
	LAS Perspective 5‡ (natural science inquiry)	3
	Free Electives	9
	Cooperative Education (summer)	Co-op
Fourth Year		
ISTE-500	Senior Development Project I	3
ISTE-501	Senior Development Project II (WI)	3
	WMC Concentration Courses	6
	LAS Immersion 2, 3	6
	LAS Perspective 6 (scientific principles)	3
	Free Elective	3
	LAS Electives	6
Total Semester Credit Hours		**126**

Please see General Education Curriculum–Liberal Arts and Sciences (LAS) for more information.

(WI) Refers to a writing intensive course within the major.

* Please see Wellness Education Requirement for more information. Students completing bachelor's degrees are required to complete two different Wellness courses.

‡ Students satisfy this requirement by taking either a 3 or 4 credit hour lab science course. If a science course consists of separate lecture and laboratory sections, students must take both the lecture and the lab portions to fulfill the requirement.

§ Students satisfy this requirement by selecting one of the following four credit options: General Biology (BIOL-101) and General Biology Lab (BIOL-103); General and Analytical Chemistry (CHMG-141) and General and Analytical Chemistry (CHMG-145); or College Physics (PHYS-111).

Concentrations

Web Application Development

Course	
ISTE-442	Secure Web Application Development

ISTE-444	Web Server Development and Administration

Mobile Application Development

Course	
ISTE-454	Mobile Application Development I
ISTE-456	Mobile Application Development II

Wearable and Ubiquitous Development

Course	
ISTE-358	Foundations of Wearable and Ubiquitous Computing
ISTE-458	Advanced Topics in Wearable and Ubiquitous Computing

Project Life Cycle

Course	
NSSA-370	Project Management
ISTE-430	Information Requirements Modeling

Database

Course	
Choose two of the following:	
ISTE-432	Secure Web Application Development
ISTE-438	Web Server Development and Administration
ISTE-470	Data Mining and Exploration

Admission requirements

Freshman Admission

For all bachelor's degree programs, a strong performance in a college preparatory program is expected. Generally, this includes 4 years of English, 3-4 years of mathematics, 2-3 years of science, and 3 years of social studies and/or history.

Specific math and science requirements and other recommendations

- 3 years of math are required and pre-calculus is recommended
- Requires chemistry or physics and strongly recommends both.
- Computing electives are recommended

SAT (EBRW+M)
1280 -1450

ACT Composite
29-34

Transfer Admission

Transfer course recommendations without associate degree

Courses in computer science, calculus, liberal arts; calculus-based physics, chemistry, or biology

Appropriate associate degree programs for transfer

AS degree in computer science, engineering science, or liberal arts

Additional information

Global opportunities

The web and mobile computing degree is offered at RIT's main campus, in Rochester, NY, and at RIT Croatia's campuses in Dubrovnik and Zagreb. Because the same curriculum is offered in all three locations, students may spend a semester abroad learning about the Croatian culture without any negative impact to their schedule of studies. Furthermore, in their senior year all students take Senior Development Project I,II (ISTE-500, 501), a year-long course in which teams are composed of students from RIT's main campus and both RIT Croatia campuses. Whether students choose to study abroad or remain in Rochester, they will be working side-by-side with their peers from across the world.

Effective fall 2013, RIT converted its academic calendar from quarters to semesters.

View this program's information from the retired quarter calendar

Programs of Study

Computing and Information Technologies

Bachelor of science degree

Stephen Zilora, Chair
585-475-7645, Steve.Zilora@rit.edu

http://cit.rit.edu/

Program overview

Students in the computing and information technologies major are characterized by their hands-on approach to technology. They are designers and builders, but primarily they're enablers. Students approach complex problems and create custom solutions that help users meet their goals. They play an integral role in any modern organization, often working behind the scenes to deploy technology where it's needed most.

That versatility is the core principle of our major. People are interacting with computers more than ever before. With that comes a need for professionals that have the broad practical skills to facilitate those interactions across a variety of sectors. Not only do computing and information technology students learn to implement complex systems, but they become well versed in their management as well. Every day, more companies are realizing the benefits that IT professionals bring to the table.

Plan of study

A defining aspect of the computing and information technologies curriculum is the breadth of technologies and the focus on integration. Students learn how to solve problems and find ways to make it work. Course work prepares students to be not just technical wizards, but also communicators and facilitators, enabling them to be successful throughout their career. Building on the core courses, students can further their skills in two separate areas or establish even greater depth in a single area. Possible areas of concentration include web administration, database, networking and communications, web development, and enterprise administration.

Cooperative education

The major requires students to complete two blocks of cooperative education. Students may pursue co-op placements after completing their second year of study.

Curriculum

Computing and information technologies, BS degree, typical course sequence

Course		Sem. Cr. Hrs.
First Year		
ISTE-120	Computer Problem Solving: Information Domain I	4
NSSA-102	Computer System Concepts	3
MATH-131	LAS Perspective 7A (mathematical): Discrete Mathematics	3
ISTE-121	Computer Problem Solving: Information Domain II	4
CSEC-102	Information Assurance and Security	3
MATH-161	LAS Perspective 7B (mathematical): Applied Calculus	4
COMM-142	Introduction to Technical Communications	3
ASCS-010	Year One	0
	First Year Writing	3
	LAS Perspective 1 (ethical)	3

	LAS Perspective 3 (global)	3
	Wellness Education*	0
Second Year		
NSSA-241	Introduction to Routing and Switching	3
NSSA-220	Task Automation with Interpretive Languages	3
ISTE-230	Introduction to Database and Data Modeling	3
NSSA-221	System Administration I	3
STAT-145	Introduction to Statistics I	3
ISTE-140	Web and Mobile I	3
ISTE-240	Web and Mobile II	3
ISTE-099	IST Second Year Seminar	0
	LAS Perspective 2 (artistic)	3
	LAS Perspective 5 (natural science inquiry)	3
	LAS Elective (WI)	3
	Wellness Education*	0
	Cooperative Education (summer)	Co-op
Third Year		
ISTE-260	Designing the User Experience	3
ISTE-430	Information Requirements Modeling	3
	CIT Concentration Courses	9
	LAS Perspective 4 (social)	3
	LAS Perspective 6 (scientific principles)	4
	LAS Immersion 1	3
	Free Electives	6
Fourth Year		
ISTE-500, 501	Senior Development Project I, II (WI)	6
	CIT Concentration Courses	9
	LAS Immersion 2, 3	6
	Free Electives	9
Total Semester Credit Hours		**126**

Please see General Education Curriculum-Liberal Arts and Sciences (LAS) for more information.
(WI) Refers to a writing intensive course within the major.
* Please see Wellness Education Requirement for more information. Students completing bachelor's degrees are required to complete two different Wellness courses.

Concentrations

Database applications

Choose three of the following:	
ISTE-330	Database Connectivity and Access
ISTE-432	Database Application Development
ISTE-434	Data Warehousing
ISTE-436	Database Management and Access

ISTE-438	Contemporary Databases
ISTE-470	Data Mining and Exploration

Enterprise administration

Required courses	
NSSA-320	Configuration Management
NSSA-322	Systems Administration II
Choose one of the following:	
NSSA-244	Virtualization
NSSA-370	Project Management
NSSA-422	Storage Architectures
NSSA-423	Scalable Computing Architectures
NSSA-425	Data Center Operations
NSSA-427	Scalable Web Services Architectures

Networking and communications

Required course	
NSSA-245	Network Services
Choose two of the following:	
NSSA-242	Wireless Networking
NSSA-370	Project Management
NSSA-441	Advanced Routing and Switching
NSSA-443	Network Design and Performance
NSSA-445	Mobile Ad-Hoc and Sensor Networks

Web development

ISTE-340	Client Programming
ISTE-341	Server Programming
SWEN-383	Software Design Principles and Patterns

Admission requirements

Freshman Admission

For all bachelor's degree programs, a strong performance in a college preparatory program is expected. Generally, this includes 4 years of English, 3-4 years of mathematics, 2-3 years of science, and 3 years of social studies and/or history.

Specific math and science requirements and other recommendations

- 3 years of math are required and pre-calculus is recommended
- Requires chemistry or physics and strongly recommends both.
- Computing electives are recommended

SAT (EBRW+M)
1280 -1450

ACT Composite
29-34

Transfer Admission

Transfer course recommendations without associate degree

Courses in computer science, calculus, liberal arts; calculus-based physics, chemistry, or biology

Appropriate associate degree programs for transfer

AS degree in computer science, engineering science, or liberal arts

Additional information

Global opportunities

The computing and information technologies degree is offered at RIT's main campus, in Rochester, NY, and at RIT Croatia's campuses in Dubrovnik and Zagreb. Because the same curriculum is offered in all three locations, students may spend a semester abroad learning about the Croatian culture without any negative impact to their schedule of studies. Furthermore, in their senior year all students take Senior Development Project I,II (ISTE-500, 501), a year-long course in which teams are composed of students from RIT's main campus and both RIT Croatia campuses. Whether students choose to study abroad or remain in Rochester, they will be working side-by-side with their peers from across the world.

Effective fall 2013, RIT converted its academic calendar from quarters to semesters.

View this program's information from the retired quarter calendar

Appendix G

IDP Pre and Post Findings

This section details the Wilcoxon Signed Rank test results for each measure and condition.

Table G.1: Wilcoxon Signed Rank Test Results for the Sympathy IDP Questions Comparing Pre and Post Responses (Two-Tailed)

	No. Part.	**Pre Mdn (IQR)**	**Post Mdn (IQR)**	***z***	**p-value**
Lectures	67	5 (0.75)	4.75 (0.875)	-0.075	0.47
Project	87	4.75 (0.875)	4.75 (1)	-1.18	0.118
Stakeholder	91	4.75 (0.875)	4.5 (1)	-1.72	0.043*
Team Member	65	4.75 (1)	4.5 (1.25)	-1.3	0.096

Note. Asterisk (*) denotes significance at α=0.05, two-tailed.

Table G.2: Wilcoxon Signed Rank Test Results for the Vulnerability IDP Questions Comparing Pre and Post Responses (Two-Tailed)

	No. Part.	**Pre Mdn (IQR)**	**Post Mdn (IQR)**	***z***	**p-value**
Lectures	67	3.5 (1.5)	4 (1.5)	0.152	0.560
Project	87	4 (1.25)	4 (1.5)	0.139	0.555
Stakeholder	91	3.5 (1)	3.5 (1)	0.511	0.695
Team Member	65	4 (1.75)	3.5 (1.25)	-0.391	0.348

Note. Asterisk (*) denotes significance at α=0.05, two-tailed.

Table G.3: Wilcoxon Signed Rank Test Results for the Fear IDP Questions Comparing Pre and Post Responses (Two-Tailed)

	No. Part.	**Pre Mdn (IQR)**	**Post Mdn (IQR)**	***z***	**p-value**
Lectures	65	4 (1)	4 (1.5)	0.245	0.597
Project	87	4 (1.5)	4 (1.5)	-0.692	0.244
Stakeholder	90	4 (1.38)	4 (1.5)	1.17	0.879
Team Member	65	4 (1.5)	3.5 (1.5)	-0.425	0.335

Note. Asterisk (*) denotes significance at α=0.05, two-tailed.

Table G.4: Wilcoxon Signed Rank Test Results for the Uncertainty IDP Questions Comparing Pre and Post Responses (Two-Tailed)

	No. Part.	**Pre Mdn (IQR)**	**Post Mdn (IQR)**	***z***	**p-value**
Lectures	67	3 (1.33)	3 (1.33)	-0.681	0.248
Project	87	3 (1.33)	2.67 (1.33)	0.307	0.621
Stakeholder	91	3 (1.67)	2.67 (1.33)	0.682	0.752
Team Member	65	2.67 (1.33)	2.33 (1.67)	0.355	0.639

Note. Asterisk (*) denotes significance at α=0.05, two-tailed.

Table G.5: Wilcoxon Signed Rank Test Results for the Coping IDP Questions Comparing Pre and Post Responses (Two-Tailed)

	No. Part.	**Pre Mdn (IQR)**	**Post Mdn (IQR)**	***z***	**p-value**
Lectures	67	3 (1.5)	2.5 (1.5)	-1.83	0.034*
Project	87	3 (2)	3 (1)	1.46	0.927
Stakeholder	91	2.5 (1.5)	2.5 (1.5)	0.832	0.797
Team Member	65	2.5 (2)	2.5 (2)	0.444	0.671

Note. Asterisk (*) denotes significance at α=0.05, two-tailed.

Table G.6: Wilcoxon Signed Rank Test Results for the Discomfort IDP Questions Comparing Pre and Post Responses (Two-Tailed)

	No. Part.	**Pre Mdn (IQR)**	**Post Mdn (IQR)**	***z***	**p-value**
Lectures	66	2.25 (1.25)	2.25 (1.5)	0.376	0.646
Project	86	2.25 (1.44)	2.25 (1.5)	0.443	0.671
Stakeholder	90	2 (1.19)	2.25 (1.25)	0.024	0.509
Team Member	65	2.25 (2)	2 (1.5)	-0.813	0.208

Note. Asterisk (*) denotes significance at α=0.05, two-tailed.

Appendix H

Student Prioritization of Methods

This section details the student-ranked educational methods proposed during the interview study. The educational methods included *resources, methods, and course structure* options for teaching accessibility. These results are discussed in Chapter 10.

Table H.1: Student-ranked resources by weighted average

	Rank 1	**Rank 2**	**Rank 3**	$\bar{x}$
APIs or programming frameworks with accessible features	38	24	13	1.535
Examples of accessible technologies	34	13	14	1.246
Accessibility guidelines and regulations	10	24	22	0.878
Automated software accessibility evaluation tools	8	14	23	0.658
List of professors that specialize in accessibility	9	16	12	0.623
Online courses or tutorials	9	10	14	0.535
Books or websites on accessibility	3	5	8	0.237
Guest speakers with a disability	2	4	6	0.175
List of organizations that support individuals with a disability	1	4	2	0.114

Table H.2: Student-ranked topics by weighted average

	Rank 1	**Rank 2**	**Rank 3**	$\bar{x}$
How to test software for accessibility	25	28	26	1.377
Gathering software requirements related to accessibility	29	23	15	1.298
Incorporating accessibility in the software development life cycle	13	19	18	0.833
Accessibility devices	12	13	7	0.605
Authoring website content	12	7	18	0.596
Disability etiquette	8	12	14	0.544
Communication preferences of different individuals	9	8	10	0.465
Deaf culture	6	4	6	0.281

Table H.3: Student-ranked course structure by weighted average

	Rank 1	**Rank 2**	**Rank 3**	$\bar{x}$
Create an elective course on accessibility that counts towards my degree	48	40	23	2.266
Add accessibility requirements within existing coursework and classes	32	26	38	1.706
Ability to take courses outside my college that will count towards my major	20	33	29	1.422
Add a required course for my major	14	13	19	0.798

Appendix I

Course Schedules and Rubrics

This section contains course schedules and rubrics delineating how accessibility was integrated within the two required courses on Human-Computer Interaction (*Human-Centered Requirements and Design* and *Designing the User Experience*).

SWEN 444-02 Human Centered Requirements and Design

[Syllabus](#)
[Project Description](#)
[Research Paper](#)
[Class Activities](#)

Class Schedule

Week	Topics	Readings	Activity*	Project Deliverables*
1 1/14	Introduction to UX Syllabus Project Introduction UX and Software Eng. UX Life Cycle	Ch. 1, 2	**Brainstorm project ideas and problem selection** **Practice Web App**	**Project teams, project startup** **Project Description** **Project Status Report Template** **Project Grading Rubric**
2 1/21	No class 1/21 Contextual Inquiry Contextual Analysis	Ch 3, 4	**Accessibility Panel Events** **Write a system concept statement and then conduct interviews**	**#0 Project selection, set up team status repo** for contextual inquiry and later user testing (1/27 **Interactive Design Requirements Template**
3 1/28	Contextual Analysis (cont) Research Paper Design Requirements	Ch 5	**Work roles and work flow** **Work Activity Notes** **WAAD**	**#1 Contextual Inquiry and Analysis** (2/3) **Research Paper** **Research Paper Rubric**
4 2/4	Design Modeling	Ch 6	WAAD (cont) **Requirements extraction** **Social model** **HTA modeling**	**#2 WAAD Diagram and Requirements** (2/10)
5 2/11	Design Thinking Conceptual Design	Ch 7, 8	Design modeling (cont) **Construct a persona** **Ideation, Sketches, Storyboarding**	**Research Paper proposal** (2/13) **#3 Design Models** (2/17) **Practice Web App (First class of the week)**
6 2/18	Design Production Prototyping **Exam 1** (2/21 or 2/22)	Ch 9, 11	Ideation, Sketches, Storyboarding (cont) **Intermediate design**	**Interactive Design Template** **#4 Conceptual and Intermediate Design** (2/26
7 2/25	No class 2/27 Evaluation Introduction Cognitive Walkthrough	Ch 12, 13	**Cognitive Walkthrough Worksheet** **Project Cognitive Walkthrough** (3/3)	
8 3/4	Affordances Design Guidelines	Ch 20,21,22 Design Patterns	**Design Principles and Guidelines**	**Mid Term Team Peer Review** (3/6) **Research Paper Beta** (3/8)

9 3/11	Spring Break			**#5 Detailed Design** (3/19)
10 3/18	Design Guidelines (cont) Heuristic Evaluation	Ch 22 See myCourses: "Ten Usability Heuristics" Web, Mobile, Responsive Design	**Practice Heuristic Evaluation (3/20)**	**Recruit four more users** for usability testing **Heuristic Evaluation Worksheet** **#6 Heuristic Evaluation Notes** (3/24)
11 3/25	User Testing Evaluation Analysis and Reporting	Ch 10, 14, 15, 16 Descriptive and Inferential Methods	**Quantitative Data Analysis (3/31)** **Accessability Panel Event (3/28)**	**Test Plan Template** **Informed Consent Form** **#7a Test Plan (3/31)**
12 4/1	Color Icons Text Grouping **Exam 2** (4/4 or 4/5)		**Color-Icon-Text-Grouping**	**Begin user testing** **#7b Programmed Prototype (beta) (4/3)** **Research Paper** (4/7)
13 4/8	Information Visualization Universal Usability Internationalization	See myCourses: Readings: Cultural factors, accessibility links + video Principles of Universal Design W3 Web Accessibility	Start informal research paper talks as time permits	**Continue user testing** **#8 Raw Test Results, Consent Forms, Data A**
14 4/15	Non-Traditional Interfaces			**#9 Presentation, Final Prototype** (4/21)
15 4/22	Project Presentations			**Final Team peer review** (4/28)
16 4/29	Course Review and Reflection			

The final exam: Section 01: Tuesday 5/7/19, 10:45am - 1:15pm in GOL 1520/30
Section 02: Friday 5/3/19, 10:45am - 1:15pm in GOL 1550
* Dropbox submissions are due at 11:59PM on the due date unless otherwise indicated by the instructor.

Last Rev: DATE WILL APPEAR ON PUBLISH

Presentation (50 pts)			
Content (45 pts)			
System concept summary			
Design and usability requirements			
Discussion of design evolution and rationale from concept to detailed design			
Task based system demo, trace to requirements, how were usability requirements met, (30 pts)			
Evaluation and reporting - discuss significant formative evaluation findings, your usability testing data analysis and findings, changes made as a result of usability testing			
Project reflection			
Style (5 pts)			
Conveyed message/info clearly, prepared, professional, time used effectively, answered questions appropriately			
	Total	**0**	**of 750**

Syllabus Calendar and Course Outline (subject to change)

Week	Topics	Assignments
1 M Jan 25 **W Jan 27**	Intro to Human Computer Interaction Norman: Affordances, Signifiers, Mapping, Feedback, Constraints, Visibility, Conceptual Models, Seven Action Steps	Read Norman chapters 1-4 Assign: Exercise 1 (due 3W)
2 M Feb 1 **W Feb 3**	Completing surveys Human Abilities	Read Dix, ch 1 Read materials on myCourses.
3 M Feb 8 **W Feb 10**	Vision: Perception Vision: Gestalt Principles of Grouping Vision: Bertin's Visual Variables, Info Graphics	Read Johnson, ch 1+2 **Due Feb 10:** Exercise 1 Read Johnson, ch 3+4+5
4 M Feb 15 **W Feb 17**	Teams: Group development, brainstorming, consensus, groupthink, bias, Active listening, hidden agendas, team formation Data Gathering: Ethnographic observation, field notes, contextual inquiry, questionnaires	Read materials on myCourses. Read Dix: 9.1-2, 9.4-6, 13.3.5
5 M Feb 22 **W Feb 24**	In-class presentations of Exercise 2 Discussing expectations for Exercise 3 Conducting Interviews with Users, Focus Groups	**Due Feb 22: Exercise 2 (in-class presentation by the group)** Read materials on myCourses.
6 M Feb 29 **W Mar 2**	Interaction Styles, WIMP, Navigation Design Input: Text Entry, Positioning/Pointing	Read Dix, ch 2+3+4 (optional: ch 8)
7 M Mar 7 **W Mar 9**	Output: Displays, 3D, Controls, Paper, Eye Tracking Technology and Methods Design Rules: Principles and Heuristics	**Due March 7: Exercise 3** Read Dix, ch 7
8 M Mar 14 **W Mar 16**	Design Rules: Standards and Guidelines, Guidelines for Good Graphic Design Representing Data: User Profiles, Personas, User Scenarios	Read Dix, ch 5 Read materials on myCourses.
Spring Break	**Spring Break**	**Spring Break**
9 M Mar 28 **W Mar 30**	User Centered Design (UCD) process Prototyping: Introduction and Techniques	Read Dix, ch 6 Read materials on myCourses. **Due March 30: Exercise 4**

10 M Apr 4 **W Apr 6**	Evaluation in HCI, Heuristic Evaluation Humans: Attention, Errors	Read Dix, 7.5 and 9.3 Read Johnson, ch 7+8+9 **Due April 6: Ex. 5, Part 1 (group)**
11 M Apr 11 **W Apr 13**	Humans: Memory How to Conduct a Usability Test	Read Johnson 10+11+12 Read Dix, 9.4 **Due April 13: Ex. 5, Part 2 (individual assignment)**
12 M Apr 18 **W Apr 20**	Empirical Evaluation: Experiment Design Empirical Evaluation: Statistical Analysis	Read materials on myCourses.
13 M Apr 25 **W Apr 27**	Students run Usability Testing, first pass Students run Usability Testing, second pass	**(Be ready for your usability test; this is Exercise 6, Part 1.)**
14 M May 2 **W May 4**	Predictive Evaluation Hierarchical Task Analysis (Teams may have in-class time to work.)	Read Johnson, ch 13+14 Read Dix, ch 15.1-3
15 M May 9 **W May 11**	Universal Design, Accessibility Terms, Laws, Web Accessibility, Access Technologies Course Wrap Up, Surveys	Read materials on myCourses. **Due May 9: Exercise 6, Part 2**
FINAL EXAM WEEK	Final Presentations	**Due on Final Exam Day: Exercise 7 (video in class)**

This calendar is tentative. Changes will be announced on myCourses.

Writing Skills

Students must demonstrate proficiency in use of the English language. University-level organization spelling, grammar, and clear expression of ideas presented are expected in all assignments submitted. The professor will not provide remedial assistance in these areas. Students needing help in basic writing skills may contact the Academic Support Center Reading and Writing Lab, at http://www.rit.edu/studentaffairs/asc/

Form and style of writing are of particular importance in business and scholarly writing. The following resources may be useful throughout your work as your writing abilities progress:

- Style: Lessons in Clarity and Grace, Williams, J.M., and Bizup, J. (Eleventh edition).
- On Writing Well, Zinsser, W., (25th anniversary edition).
- Bugs in Writing, Dupre, L., (Second edition).

Academic Integrity Policy

Questions	**Perfect**
STEP3: Did they submit a document 2-3 (or 4) page document? (0=no, 1=yes,	1
STEP3: Summarizes the observation notes of the individual team members? (0=no,	1
STEP3: Explains why you selected those environments/settings to observe? (0=no,	1
STEP3: Explains what you noticed during the observation? (0=no, 1=yes,	1
STEP3: Explains what questions this suggested to you? (0=no, 1=yes, 0.5=borderline)	1
STEP3: Explains what problems or challenges people might currently face (that you could help with)? (0=no, 1=yes, 0.5=borderline)	1
STEP3: Identifies a list of "research questions" of things you want to answer? (0=no,	1
STEP3: Includes a list of interview questions that your team members can use in Step 4. (list of interview questions not part of the page limit) (0=no, 1=yes,	1
STEP3: Include, as appendices, copies of each team members' field notes from the observation (with the team member's name on each). (0=no, 1=yes, 0.5=borderline)	1
STEP5: Did they submit a 3-4 (or 5) page document? (0=no, 1=yes, 0.5=borderline)	1
STEP5: Summarizes the interview process (e.g., what kind of people you included)? (0=no, 1=yes, 0.5=borderline)	1
STEP5: Mention what task you asked the interviewee to perform during the interview? (0=no, 1=yes, 0.5=borderline)	1
STEP5: Summarize the main themes of what you observed, grouping thematically the "commonalities" between what the interviewees said? (0=no, 1=yes,	1
STEP5: Includes some quotes from the interviews. (0=no, 1=yes, 0.5=borderline)	1
STEP5: Identifies key challenges, current problems or frustrations, hopes/desires for how things could be better? (0=no, 1=yes, 0.5=borderline)	1
STEP5: Identifies level of interest in a new app/website/technology or initial impressions of how they would like it to work? (0=no, 1=yes, 0.5=borderline)	1
STEP5: Include, as appendices, copies of each team members' interview notes (with the team member's name on each). (0=no, 1=yes, 0.5=borderline)	1
FORMAT: Each file (step 3 and step 5) should be a single, cohesive document, with consistent formatting throughout. Please submit the written assignment as a MS	1
FORMAT: Was one file called Exercise3_Step3_GroupName.pdf ? (0=no, 1=yes,	1
FORMAT: Was the other file called Exercise3_Step5_GroupName.pdf ? (0=no,	1
FORMAT: Is the line-spacing, font, and margins correct? (0=no, 1=yes,	1
FORMAT: Did they use figure captions and correct use of "See Fig. 1" etc. ? (0=no,	1
BONUS: Did the group use photos or drawings effectively? (0=none, 1=not_well,	2
SCORE (out of ten, possible to get higher)	10.4

Questions	**Perfect**
User Profile Table is included	1
- Selected appropriate characteristics	1
- Selected appropriate user groups (at least 3)	1
- Shows good detail	1
- Seems well supported by data	1
Persona (name of author is given)	1
- Based on data from field	1
- include interview data to support it	1
- picture and attractive layout	1
- age, gender, education, experience, skills, occupation, ethnicity, language	1
- context (when, where, how)	1
- what want to achieve (goals, roles, purpose, expectations)	1
- Motivation (attitude, response to pressure)	1
- Robustness (timid/aggressive, error phobic/tolerant)	1
Activity Scenario (name of author is given)	1
- High level discussion of using system	1
- Use a persona as a character	1
- rich in detail, enough to allow for analysis	1
FORMAT: Single, cohesive document, with consistent formatting throughout. Please submit the written assignment as a MS Word or PDF. (0=no, 1=yes, 0.5=borderline)	1
FORMAT: Was it called Exercise4_GroupName.pdf ? (0=no, 1=yes, 0.5=borderline)	1
FORMAT: Is the line-spacing, font, and margins correct? (0=no, 1=yes,	1
SCORE (out of ten, possible to get higher)	5.5
ASSIGNED SCORE:	
Comments from 2015:	

Rubric	Perfect	
Bonus: Did they do any extra work to improve their team's storyboard from	1	
Your document should look professional, with a consistent format	1	
Problem 1: Say the SPECIFIC heuristic guideline that justifies your analysis	1	
Problem 1: Explain the problem so that it is clear.	1	
Problem 1: if appropriate, include a screenshot to explain the problem.	1	
Problem 1: Give the severity rating for this problem.	1	
Bonus: Problem 1: you may optionally suggest a quick solution for this problem.	0.5	
Problem 2: Say the SPECIFIC heuristic guideline that justifies your analysis	1	
Problem 2: Explain the problem so that it is clear.	1	
Problem 2: if appropriate, include a screenshot to explain the problem.	1	
Problem 2: Give the severity rating for this problem.	1	
Bonus: Problem 2: you may optionally suggest a quick solution for this problem.	0.5	
Problem 3: Say the SPECIFIC heuristic guideline that justifies your analysis	1	
Problem 3: Explain the problem so that it is clear.	1	
Problem 3: if appropriate, include a screenshot to explain the problem.	1	
Problem 3: Give the severity rating for this problem.	1	
Bonus: Problem 3: you may optionally suggest a quick solution for this problem.	0.5	
Bonus: Did they discuss more than three problems?	0.5	
Name and page number in header of file	1	
Correct line spaceing, font, and margins	1	
All photos have a caption, and the text refers to "Figure 1," etc. (triple points)	1	
Did they follow the file naming conventions	1	
AUTOMATIC SCORE (out of 10, higher possible)	**11.76471**	**0**
SCORE		
COMMENTS		