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Punch Cards to Python: A Case Study of a CS0 Core Course

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ABSTRACT

There is an immense interest in teaching computer science concepts - and programming specifically - to everyone. The United States Military Academy at West Point has required every student, regardless of major, to pass a computer science zero (CS0) course for the last 50 years: From punch cards to Python. We present a history of our CS0 course and the lessons learned from the most recent redesign of the course. We review the last decade of student assessments and how they influenced the latest iteration.

We contrast the expectations of students in a CS0 course with those in a CS1 course. We discuss the national efforts to make CS accessible to all and explore the challenges unique to a CS0 course. We demonstrate similarities between our course and the Advance Placement CS Principles and show where differences are justified. We review the relevant pedagogical research for CS0 and present lessons learned over multiple iterations of the course.

Based on our current course review and implementation, we believe that Computer Science for everyone is attainable and relevant to the needs of every student.

CCS CONCEPTS

• **Social and professional topics** → **Computer science education**; *Computational thinking*; *Model curricula*; *CS1*; • **Applied computing** → *Interactive learning environments*;

KEYWORDS

Undergraduate Education, Computer Science Education, programming, programming tools, computational thinking

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1 INTRODUCTION

Interest in computing education for *everyone* has grown rapidly in the last few years. In 2016, the White House launched the *Computer Science for All* initative [38], a large-scale effort to support pre-K through 12th graders using local and state programs. The *CS for All* initiative is maintained today through the National Science Foundation (NSF) and already has awarded over 200 grants [8]. In 2017, the first Advanced Placement Computer Science Principles (AP CSP) exams were administered. The AP CSP is a multidisciplinary computing course with seven focus areas: Creativity, Abstraction, Data and Information, Algorithms, Programming, The Internet, and Global Impact [6].

Today, most colleges offer an introduction to Computer Science course (CS0) geared toward students outside the computing discipline. There is little consensus on the role of computer programming in a CS0 course, with some courses focusing exclusively on programming but others focusing on programming concepts instead of programming itself [33]. For the last 50 years, every student at West Point has been required to learn computer programming. Since 1989, it has been as part of the school's compulsory CS0 course. We believe that programming occupies a central role in computing literacy and thus about a third of our CS0 focuses on programming instruction.

This paper discusses the history of our CS0 course, reviews the challenges in teaching computer programming to novices, explores the current best-practices in programming instruction, analyzes the last decade of student feedback for our institution's CS0 course, and enumerates the most valuable lessons learned in the most recent curricula redesign.

We assert that CS0 should be a requirement for all college students. While programming instruction is inherently challenging, we maintain that a CS0 education is attainable for everyone.

2 BACKGROUND

This section explores the challenges of teaching computer science concepts, specifically programming, to novice programmers and explores the current thinking and best practices for teaching a CS0/CS1 course.

2.1 History of CS0 at Our Institution

West Point's CS0 course has changed a number of times over the past 30 years (see Figure 1). Prior to 1989, a required course taught a number of different programming languages including FORTRAN with punch cards. Starting in 1989, with the restructuring of departments, a designated CS0/CS1 course was implemented and required for all students. The course focused exclusively on programming and problem solving and was similar to an introduction to Computer Science (CS1-level) course taught at most universities. The course was originally based on Turbo Pascal, which was popular at the time. The documentation on why the language was chosen is lost; however, it is worth noting that the AP Computer Science A/AB at that time also used Turbo Pascal.

In 1996, the programming language changed to Ada 95 in order to align with other CS courses taught at our institution. In 2001, the course switched to Java.

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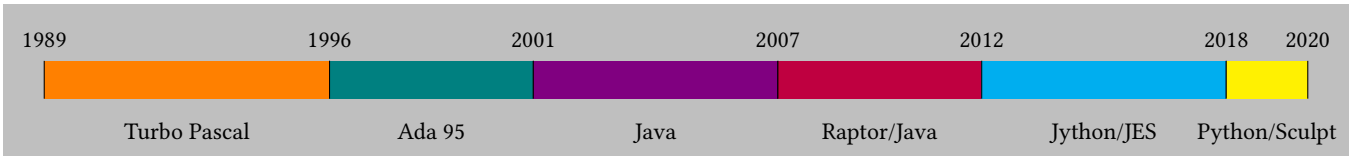


Figure 1: Course Time Line

In 2007, the course transitioned to Raptor with Java [9]. While the functionality is different from MIT's Scratch [33], many of the concepts are similar. It uses flow charts to solve a problem and generates much of the Java code for the student. The focus was on the concepts and problem-solving process which reduced the emphasis on programming.

In 2012, a pilot course using Jython [15] ran and was implemented the next year. This course used a multimedia approach [12, 14, 25]. It increased the emphasis on programming concepts, but maintained the rigor in networks, security, hardware, and ethics.

The most recent redesign, piloted in 2018, transitioned students to a Javascript (Skulpt) Python 3 implementation. The course material for the programming section borrow heavily from the *Think Like a Computer Scientist* text on Runestone Academy [26]. Section 3 provides details on the most resent course redesign.

2.2 AP CS Principles Overview

The AP Computer Science Principles (AP CSP) course covers six computational thinking practices: connecting computing, creating computational artifacts, abstracting, analyzing problems and artifacts, communicating, and collaborating. There are seven "Big Ideas": creativity, abstraction, data and information, algorithms, programming, the internet, and global impact [6, 20, 28]. Each "Big Idea," has a number of enduring understandings, learning objectives, and essential knowledge. In Section 3.1.1, we discuss how our course overlaps with AP CSP.

2.3 CS0 vs CS1 Expectations

The expectations of a CS0 course are different from those of a CS1 [10]. The AP CSP course is described as an introductory computing course [6], which we would consider a CS0. CS1 courses go into more depth on subjects that are germane to only those students who will pursue a Computer Science degree. Some examples of this include: introduction to data structures, object-oriented programming, and inheritance [7, 36].

Since programming is a "Big Idea" in AP CSP it should be in a CS0 course. Additionally, there should be an expectation of networking, cyber, and hardware lessons in a CS0 versus a CS1 course. We include all of these concepts in our redesigned course.

2.4 Relevant Pedagogical Research

Before embarking on the latest redesign of our CS0 course, we conducted a literature review. Based on the review, Problem Based Learning (PBL) [17, 37] and Worked-Out Examples [21, 30] were the best options.

The Jython Environment for Student (JES) [12, 15] version uses a PBL approach to teach programming. Students are given instruction and then directed to apply their knowledge to challenges, typically homework problems. Course scaffolding includes detailed discussion on picture objects with properties such as height, width, pixel coordinate, and color values. Students are taught basic programming constructs such as conditionals and iteration. Then students were expected to apply the programming constructs such as sequence, iteration, and selection to effect changes to a picture.

From the literature and the collective experience of the course designers, we decided to move to a worked-out examples approach in our new course in which we dedicate a large portion of the class to "walking" students through example problems. Examples give students a place to start and provide the recurring aspects of a task. Worked-out examples help novices reach early successes without cognitive overload, i.e. excessive stress [21].

Once the novice programmer has acquired a baseline set of recurring aspect knowledge and some rudimentary problem solving skills, instruction can transition from product-based to process-based worked-out examples. Product-based worked-out examples consist of only the recurring knowledge such as how to assign a variable. Process-based worked-out examples add in the *how* and the *why*, such as the realization that a variable is a location in memory with a particular value. This improves the novice programmer's problem solving skills and helps transfer these skills to high order problems and other domains.

Fading is the key to making novice programmers self-sufficient. *Forward fading* consists of removing the first part of the problem and letting the novice programmer solve the problem by providing the solution. *Backwards fading* provides the beginning of the problem and the novice programmer completes the problem [41].

There are also extraneous difficulties in learning to program, such as an Integrated Development Environment (IDE) or compiler/interpreter. These programs can be unintuitive to the novice and may contribute to the cognitive overload that novices experience in learning to program [5].

2.5 General Purpose Languages

Hiding the details of program execution makes beginner languages more accessible to novices. Beginner languages like MIT's Scratch [33] feature drag-and-drop interfaces for programming constructs like *for loops* and function declarations. There is research that suggests that using a beginner language is appropriate for a CS0 course [13]; however, some experiences suggest that beginner languages are limited in their utility for solving real-world problems [18].

2.6 Historical CS1 Failure Rates

The general consensus is that introductory programming courses are difficult [16, 39, 40]. In fact, CS1 courses have both the highest

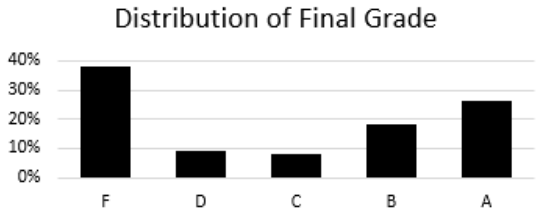


Figure 2: Historical CS1 Grades [34]

enrollment rates and the highest dropout rates at many schools [23, 24, 35]. Study after study indicates that students in introductory programming courses will generally fall into one of two groups: a highly successful group and a failing group [31, 32, 34]. Generally there are very few students in between. The most common grade in a CS1 course is an "F" followed by an "A" (Figure 2) [34].

The distribution of IQ across the general population is, by definition, a normal distribution. We asked ourselves, if student performance in an introductory programming course is a function of intelligence, why doesn't student performance exhibit the same distribution as IQ? Our research shows that student grades are not a function of cognitive capacity, development, or style; attitude or motivation; demographic factors, such as previous exposure to math or computers; or a number of aptitudes [34, 40].

Prior work argues that the highly integrated nature of the computer programming splits learners into groups that either succeed or fail [34, 40]. Computers have a multitude of components that work simultaneously to perform a single task. Programs similarly have a multitude of concepts that work simultaneously to generate the instructions for the completion of that task. The concepts must be learned serially, but no individual concept makes sense in isolation.

Since programming concepts are so integrated, a failure to understand one single concept makes it increasingly difficult to understand the next. Conversely, each idea that a student successfully grasps provides more context for reasoning about additional concepts. These students find programming concepts to be increasingly complementary and intuitive and have a greater chance of success [34, 40]. The result is one group of successful students and a second group of comprehensively confused students. This manifests in a bi-modal distribution of final grades.

Over the past seven years, the percentage of students who pass our CS0 course has been approximately 99%. Most years there are over 1,100 students taking the course. Unlike the statistics in the previous paragraphs, the AP CSP course has a passing rate of 72.7% for 2018 [4]. Passing is considered three or higher on the AP exam. The percentage to earn the lowest grade of one in 2018 is 7.6%. Because we focus on many computing topics, a student that struggles in programming does not automatically fail our course.

3 COURSE DESCRIPTION

Our redesigned CS0 course is divided into three modules: Hardware, Software, and Cyber. Table 1 enumerates the topics in each module. Each module is composed of roughly ten 75-minute lessons. The redesigned course starts with hardware then transitions to software with lessons covering operating systems, algorithms, and high level programming languages prior to programming. The course culminates with discussions on networks, data, ethics, cyber security, and cyber law & warfare.

This redesign commits much more time to hardware and cyber concepts than did previous course iterations. Over the past few years, the software module had slowly grown to give instructors more time on the topic that students struggle with the most i.e., programming. However, our direct experience from last year's pilot argues that spending more time on hardware actually does more to help students comprehend programming concepts than do additional software lessons. We believe that ordering the hardware lessons before the software lessons, and expanding the time spent on hardware, together increase student understanding of computer programming. We intend to collect the data necessary to explore that hypothesis.

Each lesson is structured so that it begins with a short quiz on the assigned reading to check knowledge and frame the discussion [3, 22]. We discuss the lesson topic for about 20-30 minutes. Every lesson concludes with a 15-20 minute in-class activity/worked out examples (Section 2.4) when students apply or explore the lesson concepts through some interactive activity. Importantly, interactivity helps to solidify concepts and make them less abstract. For example, during the robotics lesson, we watch a robot refine its stored map as it navigates obstacles in the classroom. During our web lesson, students manipulate a chat room using HTML, Javascript, and cookies.

3.1 Key Decisions

There were a number of key decisions made in redesigning the course: to keep it a CS0 instead of a CS1 course, to use a high level language instead of a beginner language, and to ensure a large overlap with the AP CS Principles course.

3.1.1 Use AP CS Principles as a model. Our course has a large overlap with the AP CSP course. We cover approximately 84% of the learning outcomes. The lesson topics to CS Principle "Big Ideas" crosswalk are found in Table 1. See Section 2.2 for an overview of AP CSP.

The major area where our course differs from the AP course is a reduced emphasis on collaborative work (a AP CSP computational thinking practice). While there are opportunities to collaborate, graded events are almost exclusively individual. Second, we also reduced emphasis in the *Data and Information* "Big Idea" in favor of other topics.

There are two concepts we think are important albeit slightly outside of the scope of the AP CSP. The first is hardware; we spend quite a bit of time discussing the hardware in a computer, then use an Arduino and robots to help solidify the concept. The second important concept is Cyber Law and warfare.

3.1.2 Follow CS0 Expectations. Trying to model our CS0 course after the typical CS1 courses is not feasible. As a compulsory course for mostly non-Computer Science majors, the design of a CS0 course is, and ought to be, different from a CS1 course. Our course trades a rigorous programming education for more breadth across IT topics [1]. However, we believe that their exposure in our CS0

Hardware		Software		Cyber	
Our Lesson Topics	AP CSP "Big Ideas"	Our Lesson Topics	AP CSP "Big Ideas"	Our Lesson Topics	AP CSP "Big Ideas"
Computers	Abstraction	OS and File Systems	Abstraction	WWW	Internet; Global Impact
Encoding data	Abstraction	Algorithms	Algorithms	The Internet	Internet
CPU	Abstraction	Languages	Abstraction	Data & Ethics	Data; Global Impact
Analog to Digital Conversion	Abstraction	Variables and Expressions	Abstraction; Programming	Threats in Cyberspace	Abstraction; Internet; Global Impact
Sensor Lab: Arduino	Creativity	Turtle Graphics & Modules	Creativity; Abstraction	Cybersecurity	Internet; Global Impact
LANs	Internet	Functions; Selection; Iteration	Programming	Cyber Law & Warfare	Global Impact
Robots & Drones	Abstraction; Global Impact	Software Development; Debugging	Programming		

Table 1: Our Lesson Topics Crosswalk the AP Computer Science "Big Ideas"

course sets a solid foundation for students that are interested in doing more in that domain.

3.1.3 Use Updated and Online Textbooks. We use three textbooks for our new course. The first is *Understanding the Digital World* [19] which covers hardware, the internet, privacy, and security. The second is *How to Think Like a Computer Scientist* online book (thinkcspy) on the Runestone Academy website [26]. The thinkcspy "book" embeds course material, videos, and knowledge checks along side executable programming challenges. This approach is well documented in [2, 27]. The third is an arduino uno that we use for labs.

The course textbook becomes stale over time (see Section 4.1). Defenses against this are readily available. Using a newer book for the non-programming portion facilitates up-to-date instruction on many of the non-programming AP CSP "Big Ideas." An on-line interactive book for programming can be modified each semester to help keep the course interactive and fresh.

3.1.4 Use of a General Purpose Language. We chose to use a general purpose language, specifically Python. Python is a popular language with a minimal syntax that is readily used to solve a variety of real-world problems. This real-world utility is limited by our choice to use a JavaScript-based Python implementation. We use JavaScript (Skulpt) so that we can integrate and assess students directly on Blackboard, our web-based LMS. Skulpt is not a complete Python implementation, it does not support C extensions, and it runs in a browser instead of a traditional operating system. Skulpt works well for our purposes, but limits students' ability to leverage external libraries and execute examples they find online.

Ideally, we want the simplicity of a beginner language, such as a simple web-based editor, with the power and utility of a general-purpose language, so that students can use their knowledge more directly to solve real-world problems.

3.1.5 Ensure Interactive Feedback. Students struggle to understand how to combine the many components of a language into a meaningful program. To reduce the amount of students' time spent on syntactic errors, we've configured our editor to detect and provide feedback on most syntactic errors. Programming challenges in the new course are accompanied by a battery of unit tests. This gives immediate and detailed feedback to the student each time the program is executed and reduces cognitive load [29]. For instance, if a student must define a function that adds two numbers together, the unit tests will verify that they've defined a function, the function is named correctly, the function takes two arguments, and the function leverages the addition operator and a return statement, and that the function returns the correct value given two numbers.

We can achieve a high-level of interactivity for programming questions through Runestone Academy's unit tests. If unit tests have been defined for a question, then students receive immediate feedback on issues with their code. A robust set of tests for code will edge students toward solving a problem on their own.

This immediate and detailed feedback has been crucial in the early programming lessons in helping students diagnose their programs' errors. We've found that these unit tests greatly reduce the time students spend randomly trying new approaches in the hope that something will work.

3.2 Transitioning to Web-Based Instruction

For the pilot course offering, we explored various web-based programming platforms. Computer programming is increasingly moving to the web. Platforms like Microsoft's Azure Notebooks, Binder, Trinket, and CodeEnvy provide programming environments and development tools through a web browser. These programming tools have the benefit of being accessible from any Internet-connected device.

An online book eliminates the need for students to install and learn a programming tool, like JES [15]. Every student is already intimately familiar with how to use a web browser, and a web-based environment is much less intimidating for a novice programmer.

3.2.1 Use an Interactive Web-Based Programming Environment (Gadget). Our *Gadget* (Figure 3) incorporates the look and feel of trinket.io's Trinket with Runestone's Python 3/Skulpt code evaluation engine. Gadgets are hosted directly within Blackboard and, like Runestone, allow students to write and execute code within the

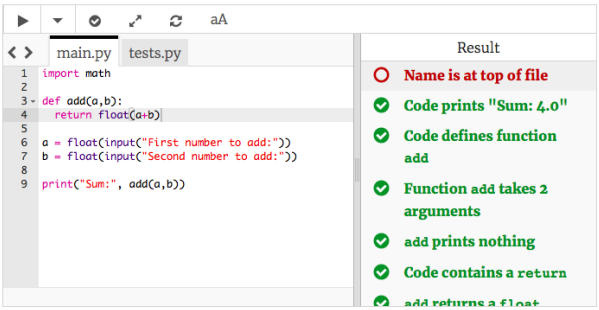


Figure 3: An IT105 Gadget incorporates the look and feel of trinket.io's Trinket with Runestone's Python 3 code evaluation engine

assigned reading webpage. Gadgets are also used for programming assessment. We are able to create programming questions alongside multiple choice, or other types of questions, when building a Blackboard assessment.

Gadgets, like Trinkets, are built on the open-source Ace editor which detects syntax errors and provides syntax highlighting. We created a robust unit-testing framework that makes it easy for instructors to incorporate a wide variety of tests in their programming questions. Gadgets also support sending code to the Python Tutor website for visual debugging [11].

3.2.2 Addressing Limitations of Web-based Programming. Our initial pilot suffered from a severe lack of integration. The hardware and cyber modules were hosted and accessed through Blackboard but the software module was hosted and accessed through Runestone. On top of requiring a second account for students, student scores had to be regularly transferred between the two systems.

In the end, we ported the relevant lessons from *How to Think Like a Computer Scientist* to Blackboard and created our own inline code execution tool (see above). Integrating with Blackboard significantly reduced the overhead of teaching programming across our nearly 30 offerings of the course. Unfortunately, the integration is not native and gadgets are slow to load and don't play well with other tools in the Blackboard ecosystem, such as the Lockdown Browser. We hope to see an LMS with a native code execution ability in the future or another more seamless plugin framework for integrating a code execution tool into a LMS.

4 STUDENT FEEDBACK ASSESSMENT

Figure 4 has three plots that show the results from the last decade of end-of-course surveys. The number of respondents per year is listed at the bottom (n). Each value statement on the end-of-course survey uses a five-value "Likert" rating scale. The scores on the rating scale, starting at one and ending at five, are: Strongly Disagree, Disagree, Neutral, Agree, and Strongly Agree. The higher the value the more a given student agrees with a particular statement. The vertical line at AY13 represents the major revision of the course from Rapter/Java to Jython depicted in Figure 1.

These results helped inform the decision to modify the course. The statement topics fall into three general categories describing: (1) textbook contribution (Figure 4a); (2) motivation (Figure 4b); and (3) confidence in being able to use programming or technology to solve future problems (Figure 4c).

The end-of-course survey value-statements are:

A6 My motivation to learn and to continue learning has increased because of this course.

C6 The textbook and readings made a major positive contribution to how much I learned.

D1 I learned to think about the implications of technology as a result of this course.

D4 If you have to learn a new piece of software that requires you to program it, how confident are you that you can use the software to solve your problem?

D5 How confident are you that you can learn and use a new piece of information technology on your own?

Our CS0 course was redesigned twice in the last decade, with pilots running in academic years 2012 and 2018. They have significantly smaller sample numbers, $n = 107$ and $n = 16$ respectively and results are annotated with *pilot*.

4.1 Textbook Utility

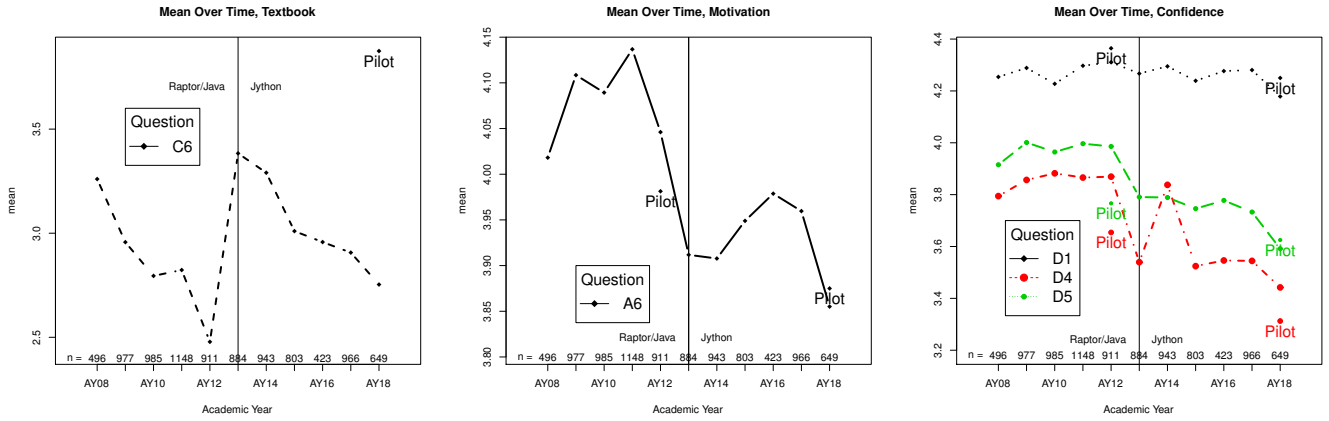
The statement with the largest downward trend for both the Raptor/Java and Jython version of the course is the one based on the perceived utility of the textbook (**C6**). Figure 4a illustrates the trend. Students initially enjoy a new textbook but after a year or two that level of satisfaction drastically reduces.

We cannot pinpoint the exact cause for the changes; however, there are a number of reasons students' satisfaction with the utility of a textbook could wane over time. Some possible causes includes the following: concern over the textbook cost, or the fact that all students must take this core course, so over time the key focus areas become known and free study guides replace the textbook. Additionally, slides and in-class examples are actively incorporated and the textbook is emphasized less by the instructors [3, 22]. In a CS0 course, like ours, a textbook falls behind current technologies quickly. Due to the small sample size, the significant increase in perceived utility for the online interactive textbook for the pilot in 2018 is not considered definitive.

4.2 Motivation

Proving relevance and engendering effort for a programming course, for a History or Chinese-language major who sees minimal value beyond graduation, is challenging. Table 4b shows the results for question **A6**. Enthusiasm for a new version of the course initially increases and then begins to drop. From 2008-2012 the values remain relatively consistent with a slight drop in 2012. In 2013, there is a significant drop, which corresponds to a transition year. The JES focused course shows a similar trend starting in 2013. Motivation initially increases for a few years and then shows a downward trend.

The first year is likely lower because students' older peers, who took the previous version of the course, cannot assist in study. It increases as the student body becomes more familiar with the content and then declines once the content becomes too well known. We speculate it is due to extensive familiarity with the course (as when numerous examples are available for students to cut and paste), staleness of tools, or predictability of instruction itself.



(a) Textbook **(b) Motivation** **(c) Confidence**

Figure 4: End of Course Survey Results

4.3 Problem Solving Using Programming or Technology

There are three survey statements related to problem-solving using programming and technology (Figure 4c). Response levels for **D1** remained consistently high over the past decade and focused on awareness of technology. Today's companies must take into account the moral and ethical issues, as well as second and third order effects of using technology. They must not be timid in learning or using new technology in their day-to-day lives. Most students have grown up in a ubiquitous technology world that likely contributes to this consistency.

Items **D4** and **D5** relate to students' confidence in their skills in programming or in using technology to solve a problem. Both of those statements have shown a downward trend over the past five years. Reasons may include: relevance of the material, presentation methods, scaffolding, textbook, and tools used. Many of these problems have been discussed herein previously.

5 LESSONS LEARNED

This section summarizes the most significant lessons learned through our redesign. These lessons are discussed in details in the other sections of this paper, but we enumerate them here so that it might be a handy summary for other schools that are also looking to implement or redesign their CS0 courses:

Include programming instruction in a CS0 course. There is no consensus on the role of programming in a CS0 course. We believe that programming is a central component of computer literacy.

Include computer hardware instruction. Our initial pilot results strongly indicate that students with a firmer grasp of computer hardware concepts will better absorb programming concepts.

Keep the textbook fresh. Our student assessments over the last 10 years indicate that the value of a CS0 textbook degrades over time.

Use a general purpose language Use Python or JavaScript, instead of a beginner language. While hiding the details of program execution makes beginner languages more accessible to novices, exposure to more challenging details may be necessary for the student to advance beyond trivial program designs [39].

Make the course web-based. If using an LMS, it is best to integrate programming. This reduces the context switch between the course material and code execution. Many coding platforms exist online so this approach doesn't deprive students of a realistic development environment.

Ensure there is interactive feedback. Immediate and detailed feedback is crucial, especially in early programming lessons, to help students diagnose programming errors.

Use the AP CS Principles Course as a guide. Every institution is different and its courses takes a unique approach; however, the AP CSP is a standard measure of what a CS0 course should look like. A good amount of overlap is desirable.

6 CONCLUSION

Our institution has been teaching Computer Science concepts and programming to every student for over 50 years. As computing becomes increasingly relevant to other disciplines, the need for every student to have a basic understanding of computers and computer programming will only increase. While the expectations for students in a CS0 course are lower than those in a CS1 course, we believe that CS0 is a valuable and necessary component of every college student's education. Decades of student assessment and feedback support the conclusion that a college-level CS0 course should be compulsory and grades indicate it is attainable for all.

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REFERENCES

[1] Kenneth L. Alford, Curtis A. Carter, Daniel J. Ragsdale, Eugene K. Ressler, and Charles W. Reynolds. 2004. Specification and Managed Development of Information Technology Curricula. In *Proceedings of the 5th Conference on Information Technology Education (CITC5 '04)*. ACM, New York, NY, USA, 261–266. https://doi.org/10.1145/1029533.1029598

[2] Christine Alvarado, Briana B. Morrison, Barbara Ericson, Mark Guzdial, and Brad Miller. 2012. *Performance and use evaluation of an electronic book for introductory Python programming*. Technical Report GT-IC-12-02. Georgia Institute of Technology.

[3] Thomas Berry, Lori Cook, Nancy Hill, and Kevin Stevens. 2010. An Exploratory Analysis of Textbook Usage and Study Habits: Misperceptions and Barriers to Success. *College Teaching* 59, 1 (2010), 31–39. https://doi.org/10.1080/87567555.2010.509376 arXiv:https://doi.org/10.1080/87567555.2010.509376

[4] College Board. 2018. AP Score Distributions. https://apscore.collegeboard.org/scores/about-ap-scores/score-distributions//

[5] Paul Chandler and John Sweller. 1996. Cognitive Load While Learning to Use a Computer Program. *Applied Cognitive Psychology* 10, 2 (Apr 1996), 151–170. https://doi.org/10.1002/(SICI)1099-0720(199604)10:2<151::AID-ACP380>3.0.CO;2-U

[6] CollegeBoard. 2017. AP® Computer Science Principles: Including the Curriculum Framework. https://apcentral.collegeboard.org/pdf/ap-computer-science-principles-course-and-exam-description.pdf?course=ap-computer-science-principles

[7] Nell B. Dale. 2006. Most Difficult Topics in CS1: Results of an Online Survey of Educators. *SIGCSE Bull.* 38, 2 (June 2006), 49–53. https://doi.org/10.1145/1138403.1138432

[8] National Science Foundation. 2018. Computer Science for All (CSforAll:RPP). https://www.nsf.gov/funding/pgm_summ.jsp?pims_id=505359

[9] John C. Giordano and Martin Carlisle. 2006. Toward a More Effective Visualization Tool to Teach Novice Programmers. In *Proceedings of the 7th Conference on Information Technology Education (SIGITE '06)*. ACM, New York, NY, USA, 115–122. https://doi.org/10.1145/1168812.1168841

[10] Dee Gudmundsen, Lisa Olivieri, and Namita Sarawagi. 2011. Using Visual Logic©: Three Different Approaches in Different Courses - General Education, CS0, and CS1. *J. Comput. Sci. Coll.* 26, 6 (June 2011), 23–29. http://dl.acm.org/citation.cfm?id=1968521.1968529

[11] Philip J. Guo. 2013. Online Python Tutor: Embeddable Web-based Program Visualization for Cs Education. In *Proceeding of the 44th ACM Technical Symposium on Computer Science Education (SIGCSE '13)*. ACM, New York, NY, USA, 579–584. https://doi.org/10.1145/2445196.2445368

[12] Mark Guzdial. 2003. A Media Computation Course for Non-majors. In *Proceedings of the 8th Annual Conference on Innovation and Technology in Computer Science Education (ITiCSE '03)*. ACM, New York, NY, USA, 104–108. https://doi.org/10.1145/961511.961542

[13] Mark Guzdial. 2008. Education: Paving the Way for Computational Thinking. *Commun. ACM* 51, 8 (Aug. 2008), 25–27. https://doi.org/10.1145/1378704.1378713

[14] Mark Guzdial and Elliot Soloway. 2002. Teaching the Nintendo Generation to Program. *Commun. ACM* 45, 4 (April 2002), 17–21. https://doi.org/10.1145/505248.505261

[15] Mark J. Guzdial and Barbara Ericson. 2016. *Introduction to Computing and Programming in Python, A Multimedia Approach* (4th ed.). Pearson, Hoboken, NJ, USA.

[16] Filiz KALELIOĞLU and Yasemin Gülbahar. 2014. The Effects of Teaching Programming via Scratch on Problem Solving Skills: A Discussion from Learners' Perspective. *Informatics in Education* 13, 1 (2014).

[17] Judy Kay, Michael Barg, Alan Fekete, Tony Greening, Owen Hollands, Jeffrey H. Kingston, and Kate Crawford. 2000. Problem-Based Learning for Foundation Computer Science Courses. *Computer Science Education* 10, 2 (2000), 109–128. https://doi.org/10.1076/0899-3408(200008)10:2;1-C;FT109 arXiv:https://doi.org/10.1076/0899-3408(200008)10:2;1-C;FT109

[18] Caitlin Kelleher and Randy Pausch. 2005. Lowering the Barriers to Programming: A Taxonomy of Programming Environments and Languages for Novice Programmers. *ACM Comput. Surv.* 37, 2 (June 2005), 83–137. https://doi.org/10.1145/1089733.1089734

[19] Brian W. Kernighan. 2017. *Understanding the Digital World.* Princeton University Press, 41 Williams Street, Princeton, New Jersey, 08540.

[20] Richard Kick and Frances P. Trees. 2015. AP CS Principles: Engaging, Challenging, and Rewarding. *ACM Inroads* 6, 1 (Feb. 2015), 42–45. https://doi.org/10.1145/2710672

[21] Chee Sern Lai, Kahirol Mohd Salleh, Nor Lisa Sulaiman, Mimi Mohaffyza Mohamad, and Jailani Md Yunos. 2014. The effects of worked example and problem solving on learning performance and cognitive load. In *4th Shanghai International Conference on Social Science 2014*. 131–143.

[22] James Lang. 2009. Choosing and Using Textbooks. https://www.chronicle.com/article/ChoosingUsing-Textbooks/44820

[23] Katherine Long. 2014. UW maxed out on computer-science space. *The Seattle Times* (2014). https://www.seattletimes.com/seattle-news/uw-maxed-out-on-computer-science-space/

[24] Katherine Long. 2016. Demand for computer science forces Washington colleges to ramp up. *The Seattle Times* (2016). https://www.seattletimes.com/seattle-news/education/with-surge-in-computer-science-majors-state-colleges-struggle-to-keep-pace/

[25] Tanya Markow, Eugene Ressler, and Jean Blair. 2006. Catch That Speeding Turtle: Latching Onto Fun Graphics in CS1. In *Proceedings of the 2006 Annual ACM SIGAda International Conference on Ada (SIGAda '06)*. ACM, New York, NY, USA, 29–34. https://doi.org/10.1145/1185642.1185648

[26] Brad Miller and David Ranum. 2014. Runestone Interactive: Tools for Creating Interactive Course Materials. In *Proceedings of the First ACM Conference on Learning @ Scale Conference (L@S '14)*. ACM, New York, NY, USA, 213–214. https://doi.org/10.1145/2556325.2567887

[27] Bradley N. Miller and David L. Ranum. 2012. Beyond PDF and ePub: Toward an Interactive Textbook. In *Proceedings of the 17th ACM Annual Conference on Innovation and Technology in Computer Science Education (ITiCSE '12)*. ACM, New York, NY, USA, 150–155. https://doi.org/10.1145/2325296.2325335

[28] Ralph Morelli, Chinma Uche, Pauline Lake, and Lawrence Baldwin. 2015. Analyzing Year One of a CS Principles PD Project. In *Proceedings of the 46th ACM Technical Symposium on Computer Science Education (SIGCSE '15)*. ACM, New York, NY, USA, 368–373. https://doi.org/10.1145/2676723.2677265

[29] Roxana Moreno. 2004. Decreasing Cognitive Load for Novice Students: Effects of Explanatory versus Corrective Feedback in Discovery-Based Multimedia. *Instructional Science* 32, 1 (01 Jan 2004), 99–113. https://doi.org/10.1023/B:TRUC.0000021811.66966.1d

[30] Roxana Moreno, Martin Reisslein, and Gamze Ozogul. 2009. Optimizing Worked-Example Instruction in Electrical Engineering: The Role of Fading and Feedback during Problem-Solving Practice. *Journal of Engineering Education* 98, 1 (Jan 2009), 83–92. https://doi.org/10.1002/j.2168-9830.2009.tb01007.x arXiv:https://onlinelibrary.wiley.com/doi/pdf/10.1002/j.2168-9830.2009.tb01007.x

[31] Andrew Petersen, Michelle Craig, and Daniel Zingaro. 2011. Reviewing CS1 Exam Question Content. In *Proceedings of the 42Nd ACM Technical Symposium on Computer Science Education (SIGCSE '11)*. ACM, New York, NY, USA, 631–636. https://doi.org/10.1145/1953163.1953340

[32] Leo Porter and Daniel Zingaro. 2014. Importance of Early Performance in CS1: Two Conflicting Assessment Stories. In *Proceedings of the 45th ACM Technical Symposium on Computer Science Education (SIGCSE '14)*. ACM, New York, NY, USA, 295–300. https://doi.org/10.1145/2538862.2538912

[33] Mitchel Resnick, John Maloney, Andrés Monroy-Hernández, Natalie Rusk, Evelyn Eastmond, Karen Brennan, Amon Millner, Eric Rosenbaum, Jay Silver, Brian Silverman, and Yasmin Kafai. 2009. Scratch: Programming for All. *Commun. ACM* 52, 11 (Nov. 2009), 60–67. https://doi.org/10.1145/1592761.1592779

[34] Anthony Robins. 2010. Learning edge momentum: a new account of outcomes in CS1. *Computer Science Education* 20, 1 (2010), 37–71. https://doi.org/10.1080/08993401003612167

[35] Anthony Robins, Janet Rountree, and Nathan Rountree. 2003. Learning and Teaching Programming: A Review and Discussion. *Computer Science Education* 13, 2 (2003), 137–172. https://doi.org/10.1076/csed.13.2.137.14200 arXiv:https://doi.org/10.1076/csed.13.2.137.14200

[36] Hamzeh Roumani. 2006. Practice What You Preach: Full Separation of Concerns in CS1/CS2. In *Proceedings of the 37th SIGCSE Technical Symposium on Computer Science Education (SIGCSE '06)*. ACM, New York, NY, USA, 491–494. https://doi.org/10.1145/1121341.1121495

[37] John R Savery. 2006. Overview of problem-based learning: Definitions and distinctions. *Interdisciplinary Journal of Problem-based Learning* 1, 1 (2006), 3.

[38] Megan Smith. 2016. Computer Science For All. https://goo.gl/F96bYV

[39] Elliot Soloway. 1993. Should We Teach Students to Program? *Commun. ACM* 36, 10 (Oct. 1993), 21–24. https://doi.org/10.1145/163430.164061

[40] J. Sorva. 2010. Reflections on threshold concepts in computer programming and beyond. *Proceedings of the 10th Koli Calling International Conference on Computing Education Research* (2010).

[41] Tamara Van Gog, Fred Paas, and Jeroen JG Van Merriënboer. 2004. Process-oriented worked examples: Improving transfer performance through enhanced understanding. *Instructional Science* 32, 1-2 (2004), 83–98.