

A RESTFUL FRAMEWORK FOR WRITING, RUNNING, AND EVALUATING
CODE IN MULTIPLE ACADEMIC SETTINGS

by

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In academia, students and professors want a well-structured and implemented framework for writing and running code in both testing and learning environments. The current limitations of the paper and pencil medium have led to the creation of many different online grading systems. However, no known system provides all of the essential features our client is interested in. Our system, developed in conjunction with Doctor Halterman, offers the ability to build modules from flat files, allow code to be compiled and run in the browser, provide users with immediate feedback, support multiple languages, and offer a module designed specifically for an examination environment.

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Chapter 1

Introduction

In academia, students and professors want a well-structured and implemented framework for writing and running code in both testing and learning environments. In a test or quiz setting, students prefer to type and have the ability to execute code. In an instructional medium such as a handout or online textbook, students would prefer to try out code snippets right in the browser without the need to install or switch to another program. Some on the other hand would like the ability to build exams and quizzes via structured text files without multiple, repetitive steps that are time consuming. Finally, automated and near-immediate grading and feedback remains a huge advantage to both parties. Our client, Doctor Halterman of Southern Adventist University, has recognized this call for a framework that satisfies these needs.

Programming tests and quizzes today often are given through the paper and pencil medium. This medium is not desirable as it does not allow for immediate feedback, which can frustrate both teachers and students. Students must wait for results and teachers must invest large amounts of time in grading students' answers. Another problem that arises due to this medium is the inability to

type and format code. For students in a high-pressure environment such as a quiz or test there is not always time to neatly write code. Erasing or revising written code can further reduce readability. As a result, teachers and students are forced to read and work with messy answers. Finally, this medium does not allow for the possibility of compiling and running code. The ability to execute code allows students to fix small mistakes such as syntax errors and other problems that do not necessarily have any implication on the testing content.

Online textbooks and other similar learning environments suffer from similar problems (i.e., no immediate feedback, and readability issues), with the addition of the need to switch to a different application completely. Using these media require students to leave the browser, have a compiler or IDE installed, and copy or write code snippets in order to try concepts out on their own.

These issues have led to the use and/or creation of two separate products: Learning Management Systems (LMS), and automated evaluation systems. An LMS (e.g., Moodle, and Edmodo) can provide a web interface for building instructional articles, exams, and quizzes and provide students with a common interface. An LMS can also serve as a secure environment for testing and quizzes, and offer features such as multiple attempts, instant feedback, and question randomization. LMSs also have the capability to integrate add-ons which can provide the ability to compile and run code written by students, such as Moodle's plug-in feature [4].

Modifying or building quizzes and exams via an LMS requires multiple, repetitive steps that are more time consuming than editing a simple flat file. In addition, current LMS do not give statistics on test and quiz properties, such as time spent per question. Existing add-ons for an LMS such as Moodle do not address this issue, and the compiler features do not contain some

of the requested properties mentioned above (e.g., immediate evaluation and feedback).

As for automatic evaluation systems, students can type and execute code, run tests, and receive immediate feedback. However, widely used solutions simply support assignments and code challenges, excluding examination environments and general practice environments.

Therefore, based on our client's interests stated above, we believe no application exists which allows users to quickly build learning modules, exams, or quizzes via structured text files for students to use, that also give them the ability to write and run code and receive immediate feedback on submitted work.

This project addresses these issues by creating a framework which provides a medium with the following goals:

- Allow professors to quickly build activities via simple flat files
- Allow students to be able to type code in an environment that provides syntax highlighting
- Allow students to compile and run code in a controlled environment
- Allow for the ability to build activities specifically for an examination environment
- Allow students and professors to get immediate statistics and feedback
- Allow for the support of multiple programming languages

Given this framework, professors can quickly and easily create quizzes, tests, and other learning environments, and students can edit and compile code and receive immediate feedback. We believe this will help professors limit time

spent on building and grading tests and quizzes, and help students focus more on actual test content, rather than on formatting and cleaning up answers.

For the remainder of our paper, we first cover the background in Chapter 2. Chapter 3 and Chapter 4 will cover our project architecture/design and testing respectively. Finally, Chapter 5 presents our conclusion on the research found and our future work on the Master's Project.

Chapter 2

Background

Currently there are virtually no systems in widespread use that provide automated feedback tailored for programming. However there are instead many different niche systems in use. The most popular systems in use in academics today are Learning Management Systems (LMS). These products provide teachers and students with a familiar medium in which to access assignments, grades, and even tests and quizzes. These systems also allow for modules to be added in order to provide new features developed by third parties. In addition to these systems there exists more focused projects that attempt to provide similar services, specifically tailored toward programming in education. In this section we explore the abilities of popular LMSs, and open source programming evaluation systems which attempt to provide similar functionality.

Our background analysis is broken into two different sections, Learning Management Systems in section 2.0.1 and automated programming evaluation systems in section 2.0.2, taking into consideration their strengths and weaknesses as follows:

- Test and quiz building

LMS	Users
Moodle	71,054,217
Edmodo	49,000,000
SuccessFactors	28,000,000
Blackboard	20,000,000
TOPYX	20,000,000
SkillSoft	19,000,000
Instructure	18,000,000
Desire2Learn	15,000,000
Cornerstone	12,400,000
Schoology	8,500,000
Meridian Knowledge Solutions	8,500,000
eLogic Learning	5,000,000
Latitude Learning	3,500,000
eFront	3,500,000
Docebo	2,100,000
Litmos	2,000,000
TalentLMS	600,000
DigitalChalk	425,000
Collaborize Classroom	350,000
Educadium	75,000

Table 2.1: The top 20 most popular LMS packages, ranked in order of total users as of 6/3/15 [5].

- Code formatting and compiling ability
- Answer evaluation and feedback

These three topics will provide a perspective on how the system functions and how well it addresses our goals.

2.0.1 Learning Management Systems

The following subsection will evaluate the LMS based systems selected for analysis. Table 2.1 shows the most popular LMS software packages [5], from which we select the two most popular LMSs (Moodle [6] and Edmodo [7]) for anal-

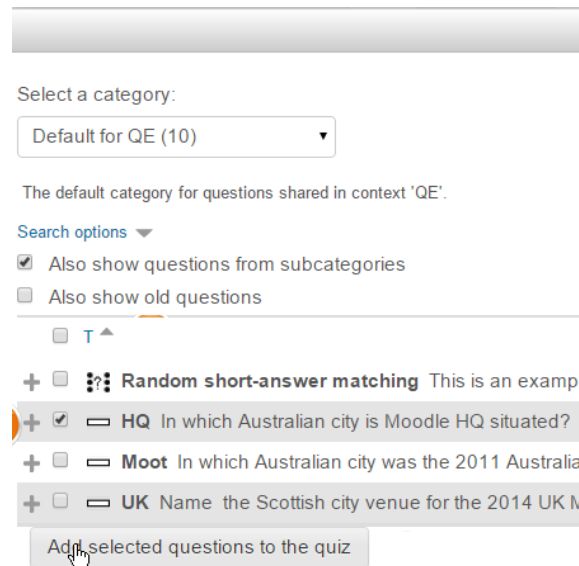
ysis along with two LMS modules for Moodle called the Virtual Programming Lab [1], and Javabrat [2].

2.0.1.1 Analysis: Moodle

Moodle [6] is a free, open-source LMS for producing modular internet-based courses that support a modern social constructionist pedagogy. Because it is open-source, Moodle has a large community contributing many modules that extend its feature set.

Test and quiz building Moodle has a quiz activity module which allows the teacher to design and build quizzes consisting of a large variety of question types, including multiple choice, true-false, and short answer questions. To make a new quiz/test assignment in Moodle, the teacher may either import a quiz from a range of different flat file formats [8], or manually add a quiz module to the course. When creating a quiz manually, the teacher must first create the quiz activity. To add a new question to the quiz's question bank, the teacher must click 'Add' and then '+ a new question'. From the next screen, the teacher must choose the specific question type. Once the question form is filled in with the question and any necessary options are added the question can be saved and added to a question bank shown in figure 2.1. The teacher must then add questions to the quiz from the question bank.

With all of the steps in manually building quizzes, teachers must invest time in adding items to question banks on top of formulating the actual question content. While importing questions from flat files is useful in avoiding this overhead, the type of questions available to be asked are still limited by Moodle's standard questions types [9].



Select a category:

Default for QE (10) ▼

The default category for questions shared in context 'QE'.

Search options ▼

☒ Also show questions from subcategories

☐ Also show old questions

☐ T ▲

+ ☐ **Random short-answer matching** This is an examp

+ ☒ **HQ** In which Australian city is Moodle HQ situated?

+ ☐ **Moot** In which Australian city was the 2011 Australia

+ ☐ **UK** Name the Scottish city venue for the 2014 UK M

Add selected questions to the quiz

Figure 2.1: A simple Moodle quiz module.

Code formatting and compiling Moodle quiz activity modules can accept multiple choice and text input. These methods allow students to type code, which is an improvement on the pencil and paper medium. However, these input methods do not allow students to properly format code, or show syntax highlighting. Similarly, students do not have the ability to execute code and see results produced by the compiler which limits the types of questions that can be presented.

Answer evaluation and feedback Moodle quiz activity modules provide the ability to evaluate and grade answers immediately and give students feedback, which is another improvement on the pencil and paper medium. Unfortunately, due to question limitations mentioned above, there is no ability to run test cases on student defined code and grade submissions automatically.

2.0.1.2 Analysis: Edmodo

Edmodo [7] is a free social learning platform for schools. It provides teachers and students with a secure way to share classroom materials, and access homework, grades.

Test and quiz building Edmodo has a quiz activity allows teachers to create online quizzes for students and receive instant feedback on grade results. Unlike Moodle, all Quizzes and Quiz questions must be created within Edmodo and cannot be imported. The steps to do so are comparable to Moodle's, and incurs similar overhead. To create a quiz in Edmodo, a teacher must create a quiz activity, and manually select a question type. Once the question form is filled in with all necessary information the question can be saved and added to a question bank.

Similarly with Moodle, Edmodo is limited by the building overhead and the types of questions available to be asked (Multiple choice, True/False, Short Answer, and Fill in the blank).

Code formatting and compiling Again, very similar to Moodle, Edmodo quiz activities can accept multiple choice and text input. These methods allow students to type code, however these input methods do not allow students to properly format code, or show syntax highlighting. To add to this, students do not have the ability to execute code and see results produced by the compiler which limits the types of questions that can be presented.

Answer evaluation and feedback Edmodo quiz activities provide the ability to get results feedback immediately, which is another improvement on the pen-

cil and paper medium. Due to question limitations mentioned above however, there is no ability to run test cases on student's code and grade submissions automatically in that manner.

2.0.1.3 Analysis: The Virtual Programming Lab

The Virtual Programming Lab (VPL) [1] is an activity module for Moodle that manages programming assignments and whose main features are:

- Students can edit program source code in the browser
- Students can run programs interactively in the browser
- Students and teachers can run tests to review the programs

Test and quiz building This activity module for Moodle is unfortunately tailored for programming assignments. Because of this, it is not possible to create an assignment in a test or quiz format.

Code formatting and compiling VPL allows files to be edited from the browser using the code editor component, as shown in figure 2.2. It also has the ability to supply initial skeleton code. This added functionality allows students to run and evaluate programs without requiring them to install compilers or IDEs. The code editor component provides formatting as well as syntax highlighting, which is useful for students both reading and writing code.

Answer evaluation and feedback VPL allows for scripts to be set to evaluate every submission, which enables students to receive feedback on their code based on test cases. However, this takes more time to set up than simply defin-

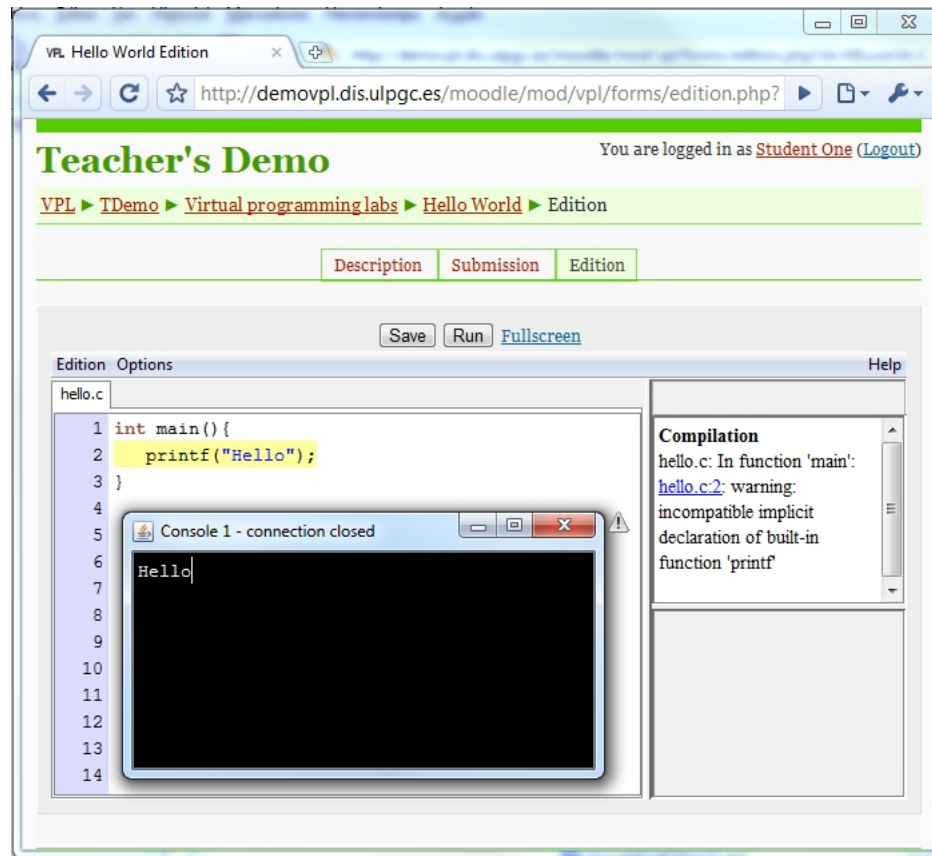


Figure 2.2: A simple VPL module assignment [1].

ing test cases and is geared more towards assignments instead of quizzes and tests.

2.0.1.4 Analysis: Javabrat

Javabrat [2] is a web-based grader useful for students learning Java and Scala languages. It is primarily in the form of a Moodle plugin that facilitates instructors to grade Java assignments.

- Students can edit program source code in the browser
- Students and teachers can add problems to be solved

- Students and teachers can run tests to review the programs and automatically grade them

Test and quiz building Similar to VPL, Javabrat is tailored towards programming assignments. Because of this, it is not possible to create an assignment in a test or quiz format.

Code formatting and compiling Javabrat allows for code to be typed directly into the browser, but does not support syntax highlighting, as shown in figure 2.3. Similar to VPL, Javabrat has the ability to provide an initial skeleton code for students to build on. This setup allows students to type out code and evaluate results without having to leave the browser.

Answer evaluation and feedback With Javabrat, program results are evaluated immediately. When a student completes a solution, it can be evaluated in the browser by running pre-defined test cases. Once the evaluation is done, Javabrat sends back an HTML report file generated by the back-end as shown in the lower part of figure 2.3.

2.0.2 Automated Programming Evaluation Systems

The following subsection will evaluate the automated programming evaluation systems selected for analysis. From our research we select three popular automated programming evaluation systems: Web-CAT [10], Turing's Craft [11], and CourseMarker [12].

1

Marks: 10

PerimeterTester

Write a PerimeterTester program that constructs a Rectangle object and then computes and prints its perimeter. Use the getWidth and getHeight methods. Also print the expected answer.

PerimeterTester.java

```

import java.awt.Rectangle;

/**
 * Constructs a Rectangle object and then computes and prints its perimeter.
 */
public class PerimeterTester
{
    public static void main(String[] args)
    {
        Rectangle r1 = new Rectangle(5, 10, 20, 30);
        double perimeter = 2 * r1.getWidth() + 2 * r1.getHeight();
    }
}

```

Check

Click Check to test your program and generate a report for the grader. You can generate reports as often as you like. Simply fix your code and click Check again.

Evaluation Summary

compile	pass
tester	pass
Total:	100%

Compiling Main Program

pass

Compiling 1 source file to /opt/glassfish-data/webLabRat/problem_repository/s

Testing Main Program

pass

Perimeter: 100.0
Expected: 100

Student Files

IMPORTANT:

When you are done with all problems, click "Submit all and finish" before the deadline. Otherwise, your homework will not be graded.

If you want to come back later to finish, click "Save without submitting"

Save without submitting

Submit all and finish

Figure 2.3: A basic Javabrat assignment example [2].

The screenshot shows the 'New Submission' interface for a student named Stephen Edwards. The interface is divided into two main sections: 'New Submission' on the left and 'Upload Your File(s)' on the right.

New Submission Section:

- Step 1:** Pick the course
- Step 2:** Pick the assignment
- Step 3:** Upload your file(s) (Currently selected)
- Step 4:** Confirm your submission
- Step 5:** View your results

Upload Your File(s) Section:

For: **CS 1(2) Project J4: Java calculator (full static checks)**

Your previous submissions for this assignment:

Total of 3

No.	Time	Score
3	08/16/06 10:06PM	44.0
2	08/16/06 05:32PM	69.0
1	08/16/06 05:26PM	28.1

Upload a single zip, jar, tar, or tgz file containing your Java source files, including your JUnit test cases. Test cases must have class names ending in "Test" or "Tests" (case-insensitive).

So far, you have uploaded the file **Java-calculator.zip** (1.4kb) for submission. You can replace this with a different file, or choose to continue.

Choose the file to upload:

Figure 2.4: A simple Web-CAT module assignment [3].

2.0.2.1 Analysis: Web-based Center for Automated Testing

The Web-based Center for Automated Testing (Web-CAT) [10] is a flexible automated grading system designed to process computer programming assignments. Its main features are:

- Provide immediate feedback based on test-cases and code coverage
- Enable flexibility and extensibility by way of a plug-in based architecture
- Provide a secure and portable product

Test and quiz building Similar to VPL, Web-CAT is tailored for programming assignments. Because of this, it is not possible to create an assignment in a test or quiz format.

Code formatting and compiling Web-CAT does not allow files to be edited from the browser. It does however have the ability to supply initial skeleton code. Without this functionality, students must use their own compiler or IDE. In Web-CAT, students are required to upload their source code to the correct assignment as shown in figure 2.4.

Answer evaluation and feedback Web-CAT uses a composite scoring system, which enables students to receive feedback on their code based on their code correctness, test completeness, and test validity. These three measures, taken as percentages, are then used to form a composite score [13]. This formula ensures that no aspect of the approach can be ignored, or the student's score will suffer. Code correctness is based solely on student written tests, unlike the other two scores. For test completeness, instructors must choose what level of coverage should be used for testing completeness, and for test validity, instructors must set specific reference tests to ensure the student's tests are accurate.

2.0.2.2 Analysis: Turing's Craft CodeLabs

Turing's Craft CodeLab [11] is the commercial equivalent to WebToTeach [14], developed to provide fully interactive, hands-on practice environments for learning computer programming. The supported topics start with the imperative programming core of Python, C, C++, and Java and then go on to address procedural and object-oriented programming. The exercises are targeted at a typical CS1 syllabus.

Its main features are:

- Students can edit and run source code in the browser

- Provide immediate feedback based on test-cases in the browser
- Provide teachers with a selection of exercises ranging from short and focused to more complicated problems intended to be used as teaching aids

Test and quiz building Because Turing's Craft is targetted towards programming assignments and challenges, it does not support quiz or exam formats.

Code formatting and compiling The Turing's Craft engine is hosted and supported by Turing's Craft and the CodeLab runs in the browser, so students are able to write and run code directly in the browser. Unfortunately, it does not support syntax highlighting.

Answer evaluation and feedback Turing's Craft CodeLab provides student with immediate feedback on submitted solutions. With each submission, the instructor's roster is automatically updated regarding solution correctness. As it is intended to be used as a teaching aid, Turing's Craft research found that CodeLab works best when required as 5-10% of a student's grade.

2.0.2.3 Analysis: CourseMarker

CourseMarker [12] was developed for the assessment of Java programming skills of CS students. CourseMarker has been tailored to the students need by teachers and students suggestions, building off of an older automated assessment tool called "Ceilidh" [15]. Its main feature is to allow students and teachers to run tests and receive in-depth metrics and assessments immediately. CourseMarker must be installed instead of accessing it through a browser.

	Exam environment	Code formatting	Immediate feedback	Multi-lang support
Moodle	X		X	
Edmodo	X		X	
VPL		X	X	X
Javabrat			X	
Web-CAT			X	X
Turing's Craft			X	X
CourseMarker			X	X

Table 2.2: A visualization of how many of this project's goals are met by each solution evaluated above.

Test and quiz building Similar to VPL and Web-CAT, CourseMarker is tailored for programming assignments. Because of this, it is not possible to create an assignment in a test or quiz format.

Code formatting and compiling CourseMarker does not allow files to be edited from the client, but it does have the ability to supply initial skeleton project files. Without this functionality, students must use their own compiler or IDE.

Answer evaluation and feedback CourseMarker provides grading results immediately once code solutions are submitted. Students receive feedback on typography, scalability, and test cases. With typography, CourseMarker checks the program layout, indentation, and usage of comments. Regarding scalability, CourseMarker attempts to use different sized datasets when possible. Lastly, CourseMarker evaluates solutions by checking for exercise dependent features defined by the teacher.

In summary, as seen in table 2.2, each of the popular solutions reviewed met different parts of our client's overall goals but none met all of them. While a few such as Web-CAT came close, many of the widely used solutions do not offer everything this project is attempting to accomplish.

Chapter 3

Project Implementation

Our system creates a RESTful web service that provides the following services:

- A quiz/test module generated from a quick and easy flat file which defines questions, options, scores, etc. in a medium that allows for code formatting and execution
- A learning module which provides an insertable interface to compile and execute code generated from a flat file which defines the problem description, skeleton code, and test-cases

Six external libraries were utilized in the development of this system, and the system contains over 2,000 lines of non-library code. In this chapter, we discuss the development approach, task delineation, system process workflow, and final deliverables for this system.

3.1 Development Approach

We implemented our system on an Ubuntu unix VM, using Node.js and jQuery in order to take advantage of modules such as Express [16] which provided robust sets of frameworks and features for web applications. While some synchronous functions were used for purposes such as writing data to file and handling compiler input/output, we generally utilized Node's asynchronous nature and Javascript's Promise objects to minimize blocking. We also made use of the Model-View-Controller design pattern in order to organize our code and system structure.

Since this system's intent focused on an exam environment, we considered security a high priority. With regards to client-side execution, since all scripts sent from the server to be executed client-side exist in a specific namespace, interaction through the console window cannot reach the code or any variables during normal execution and therefore ensured data integrity. The design of the system ensured no exam solutions ever touched the client side and all submissions were evaluated server-side. Security is covered in more detail in section 3.3.5.

We have utilized two internal Node.js modules (`fs`, `child_process`), six external modules, and two jQuery plugins in order to speed up development. All modules and plugins were licensed under the MIT license [17], with one module licensed under the BSD 2-Clause [18]. Table 3.1 lists each of these modules and their purpose in the system.

Module/Plugin	Purpose
CodeMirror	A text editor implemented in JavaScript used for styling and editing code
Express	An MVC-based web framework for Node.js used to handle client/server interactions
Body-parser	Node.js body parsing middleware used to parse JSON files
Connect-busboy	Connect middleware for busboy used to handle file uploads
Deasync	JavaScript wrappers of Node event loops used to keep from blocking threads
Fs	Simple wrappers of standard POSIX functions used to provide File I/O
Uglify-js	JavaScript parser/compressor used to minify scripts
directory-tree	Creates a JavaScript object used for displaying a directory tree.
child_process	A module which spawns a shell and executes commands within that shell

Table 3.1: Node.js modules and JS plugins used in this system

Task	Work Hours
Server Implementation	70
Examination module	85
Server-side Examination evaluation	90
Learning module	60
Administration module	80
Server-side code execution and evaluation	120
Final changes, bug fixes, testing, and documentation	60
Project Completion	565

Table 3.2: A visualization of this project's goals and rough estimate of hours taken to complete

3.2 Task Delineation

Development was broken up into seven major categories for testing and development. Table 3.2 shows an overview of major tasks, including work hours.

3.3 Architecture

Our system's architecture was distributed across both the server and client. The interactions are described in this section. The system design and interactions are illustrated in Figure 3.1, and the complete process flow is detailed in section 3.4.

3.3.1 Server-side

Node and the Express [16] framework together which handled routing REST calls acted as the Controller in this Model-View-Controller (MVC) design. The majority of the Model's business logic provided functionality such as compiling code, building and evaluating exams, and formatting/serving data such as the core client facing business logic (minified and sent to the client to execute).

3.3.2 Client-side

The View component utilized HTML and jQuery to populate the exam and provide all View related functionality. An AJAX request made by the client (if successful) returns scripts to execute which initiate the rest of the exam. The Controller component processes these AJAX calls throughout the exam period, manipulating the Model and View accordingly. An example of this interaction is a simple compile, where the client requests the server to compile code and the response updates the View.

3.3.3 Datafile Design

We use a simple flat file to generate exam content, following the Javascript Object Notation (JSON) format. The flat data file is uploaded to the server, parsed to form a JSON object, and stored. This JSON object has the following structure:

```
0 {  
1   "0": {  
2     "questionType": "code",  
3     "language": "c++",
```

```

4      "problem": "Write a C++ function called print that accepts
        an integer and prints it out.",
5      "skeleton": ["#include <iostream>\nusing namespace std;\n\n%
        READ_IN%\nint main() {\n    string x = \"printed\";\n
        print(x);\n}\n", "%READ_IN%", "//Write your code here\
        nvoid print(string x){\n    cout << x;\n}"],
6      "input": ["1"],
7      "output": ["1"],
8      "points": ["15"],
9      "difficulty": ".5"
10     },
11     "prop": {
12         "closeDate": "6-15-2018",
13         "closeTime": "13:30",
14         "allowMultiple": "false",
15         "time": "15",
16         "warn": ["10", "5"],
17         "whitelist": ["0421291", "0421292"],
18         "access": "true"
19     }
20 }

```

Data-structure 3.1: Example JSON datafile object structure

Within this structure, "questionType" can hold two values, "code" and "mchoice". This value defines whether the question is a coding question (where students are expected to write code), or a multiple choice question with randomized an-

swers (where students are expected to answer questions; e.g., what result is produced by a given code snippet). Each field serves the same function for either type of question, excluding the "input" and "output" fields (more on this later). The "language" field defines the programming language used, "problem" defines the question, "skeleton" defines the initial skeleton code, "points" provides the point value, and "difficulty" defines a difficulty level which translates into minutes ($\text{value} * 10 = \text{suggested time}$) used to produce suggested completion times. The "skeleton" field also includes an optional usage which holds a "hidden skeleton", a replace token, and a "visible skeleton" for questions that may want to hide some details from the user, instead of just the standard skeleton. We have shown this optional format in line five of the example data structure.

For coding questions, the "input" field utilizes an array that holds different test-cases. This input value can represent any input a keyboard can provide in a command-line setting. Each element in the "input" array is a different test case that will be run against student's submissions. The "output" field represents the expected output produced after running each test case using inputs (if any) from the "input" field.

Multiple choice questions on the other hand, use the "input" field differently. With this question type, the "problem" field describes the overall instructions and the "skeleton" field describes the corresponding code snippet, identical to coding questions (except it is non-editable). However, "input" utilizes a multi-dimensional array, with each internal array holding a sub-question and an array of options from which students can choose. The "output" field dictates the indices of the correct options.

The structure also contains a required "prop" field which can hold both re-

quired and optional information about the activity. The required fields "time" and "warn" are used to control how long an exam will last before auto submitting. The optional fields "closeDate" and "closeTime" denote when an exam will restrict access, "allowMultiple" defines whether students can take an exam multiple times, and "whitelist" and "access" control access to the exam. Note that the server's internal time-zone may not match your own, which can cause date specific properties to work unexpectedly.

Since our system utilizes the JSON format, code cannot contain line breaks. Instead, line breaks must be replaced with a Line Feed ("\n"). This can cause the creation of datafiles to become an arduous effort. To address this issue, skeleton code wrapped with predefined tokens (start: "_<_", end: "_>_") can instead be used with the server automatically converting line breaks to Line Feeds. An example of this format can be seen in Figure .4.

3.3.4 Administrative Portal

Our system includes an administrative side where both datafiles and test results can be seen. These files are organized by course and exam. For datafiles, authenticated users can upload datafiles, edit them, and remove them. Result files can also be viewed, but not uploaded, edited, or removed. However, exams have the option to generate a report by walking through each of the result files and displaying it in a printable modal. These interfaces can be seen in Figures .5, .6, .7.

3.3.5 Testing Security and Integrity

Security is important for any sort of testing module. Since the AJAX call's response calls the script containing the necessary logic for the client, it exists only in that namespace. Because of this namespace, interaction through the console window cannot reach the code or any variables during normal execution. In order to manipulate anything, a malicious user would have to use browser developer tools such as breakpoints, and even then it would not accomplish anything beyond using their allotted time and distort the presentation of questions. No exam solutions ever touch the client side and all submissions are evaluated server-side.

As an added layer of protection, any variables created are local variables and locked using the `Object.freeze()` Javascript method. This method prevents malicious users from adding new properties to the frozen object; prevents existing properties from being removed; and prevents existing properties, or their enumerability, configurability, or writability, from changing. In essence, the object is effectively immutable. This method is mainly used to lock the answers given from the multiple-choice part of the exam once students begin the programming section in order to keep students from checking their answers in the multiple-choice section.

Regarding server-side code execution, students could attempt to take advantage of this system's architecture and submit malicious code. We decided on using both Unix filesystem privileges as well as process monitoring to help protect the system.

Lastly, we suggest that a proctor be used in addition to these features as we have no control over student collaboration and communication. Similarly, prod-

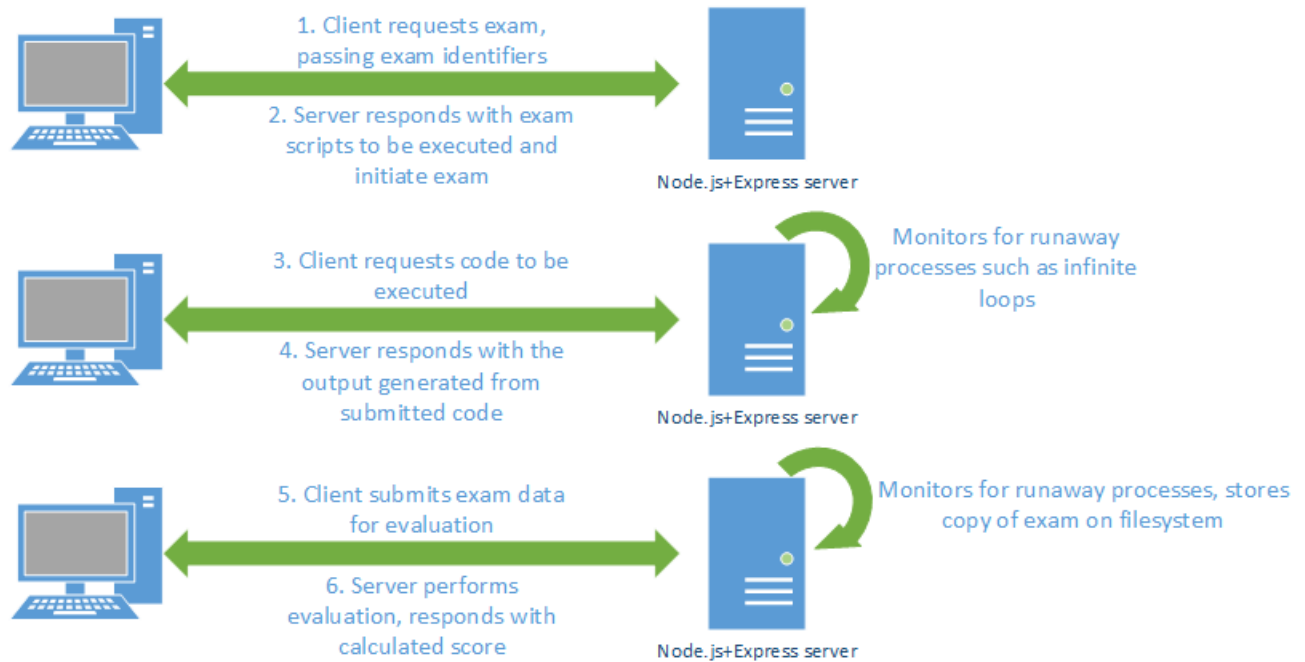


Figure 3.1: A diagram illustrating the high-level process flow.

ucts such as Respondus' LockDown Browser [19] can also provide additional security by way of a custom browser that locks down the testing environment. Together, these layers of security limit the ways in which students were able to collaborate or cheat in these tests.

3.4 System Process Workflow

The system consists of a back and forth between the client and the server. This process is broken up into four main stages: Module selection, module execution, code compilation, and final evaluation. We have shown these interactions in figure 3.1.

3.4.1 Module Selection

This first step initializes the system. For an exam or quiz, the client will first post a request to the server's /getModuleSelector endpoint. This endpoint minifies and sends a script that provides the user with a modal and some additional logic that allows the user to request the specific quiz or exam. This information includes student ID, course ID, and exam ID.

Once submitted, the server parses this information from the requested JSON datafile, inserts those values into Hyper Text Markup Language (HTML) templates, and sends the HTML code along with a minified script that holds the client facing business logic. This templating allows the system to build and serve an exam quickly.

If a learning module is requested, the request should specify as such and include the module ID. The full module would then be sent in the response, and skips to subsection 3.4.3.

3.4.2 Module Execution

At this point in the system's workflow, the client will now have the full code which will execute and append it to the specified Document Object Model (DOM) element. Once the student enters the exam and selects 'Begin', the exam and timers will start. When the exam's timer elapses, the exam will then automatically submit all available data to the server for evaluation. Figure 3.2 shows an example exam built through this process.

Practice Exam

Enter or modify the code below and press 'Compile' to execute and view results.

43:43

Submit Exam

Complete the following function that counts the even numbers in an integer vector. For example, if vector `vec` contains the elements 3, 5, 2, -1, and 2, the call

```
count_evens(vec)
```

would evaluate to 2, since `vec` contains two even integers. The function returns zero if the vector is empty. The function does not affect the contents of the vector. A simple test main function is provided for your convenience.

```

1 #include <iostream>
2 #include <vector>
3 using namespace std;
4
5 int count_evens(const vector<int>& v){
6
7     return -1; //Replace with working code
8
9 }
10
11 int main() { // Make vector
12     cout << "Enter vector size: ";
13     cin >> size;
14     vector<int> v(size);
15     // Populate the vector
16     for (int i = 0; i < size; i++) {
17         cout << "Enter element " << i << ": ";
18         cin >> v[i];
19     }
20
21     // Test the function
22     cout << count_evens(v);
23 }
24

```

Inputs will be read in order for every line read performed.

New input: +

Current inputs: ▼ -

Compile

Suggested time:

20:40

Commit

<< Prev

Next >>

Figure 3.2: A screenshot displaying an exam coding question built from a datafile.

3.4.3 Code Compilation

Once the exam or learning module has started, users can compile and run code. The response will send the language (currently we support C++11 and Python 3.X), code, and any inputs separated by newlines to be read in as standard input. It should be noted that for the quiz and exam modules, compilation can only occur once a student has completed the multiple-choice section. The system will record and freeze all answers from the multiple choice section once any compilation is initiated.

When compiling, the server creates a temporary directory by concatenating the current datetime and a random integer ranging from 0 to 9999. Once the server creates the directory, the code compiles (if necessary) and executes, piping in the inputs (if any) as standard input. The response returned will hold the generated output or error.

3.4.4 Final Evaluation

This section of execution marks the final part in the system's workflow and only applies to the quiz and exam module. Two conditions can initiate this process: reaching the exam's time limit or the user clicking the submit button. Once the server responds, a modal window displays the calculated score.

The server processes the submitted exam data and writes the results to a result file (identified by the student's ID). For grading multiple-choice questions, comparing the submitted answers' indices with values from the datafile indicate correctness. Similarly for code questions, comparing the outputs of each testcase to the expected outputs from the datafile determine correctness. For coding problems, all test cases must pass to award points.

3.5 Summary

This chapter described the project solution's architecture, design, and process flow. It detailed the business logic and syntax necessary to understand the overall application and create well-formed datafiles and therefore exams.

Chapter 4

Testing and Evaluation Results

This chapter reviews the software requirements, the evaluation process to test those requirements, and the results of that evaluation.

Our evaluation relies on a simple pass/fail process. We verified component requirements through user testing, integration testing and visual inspections of the system and show a check sheet that lists the requirements completion status.

4.1 Integration and User Testing

Full functionality testing by performing consistent integration testing along with multiple user testing sessions aided in finding small bugs and useful additions. Figure 4.1 sums up the results of the integration and user testing performed.

- ✓ Modules are served correctly and consistently across platforms.
- ✓ Questions, sub-questions, and answers are all generated and displayed correctly.
- ✓ Server receives, compiles, and runs submitted code and reports results correctly.
- ✓ Submissions are received and results are reported successfully.
- ✓ All question specific test-cases run and evaluate successfully.
- ✓ Exam results are immediately reported to user and stored successfully.

Figure 4.1: Evaluation checklist.

4.1.1 User Testing

Coordinating with Dr. Halterman, Southern Adventist University's CPTR-124 students used the system for both practice and actual exams. Through this user testing, the system evolved based on feedback and performance observations.

The following summary describes the testing results and feedback received:

- Practice exams: The feedback received was positive enough to warrant testing the system in an actual exam. No problems encountered.
- Actual exams: The feedback received was positive and very useful as users' experience revealed a few bugs such as runaway processes, and quality of life adjustments such as warnings and extra datafile customization.

4.2 Evaluation

User and integration testing and feedback paired with visual inspections show that our solution meets the requirements and goals set for this project. After implementing user testing feedback, performance evaluation showed that the system was able to handle loads with a negligible performance hit.

During the first testing session, an interaction between Node's `child_process.exec` timeout functionality and infinite loops caused timeouts to fail and the CPU usage to rise to 99% as these programs kept running. After the cause for these run-away processes was found, we implemented a monitoring solution that kept these programs from continuing infinitely. The peak performance impact after the fix was implemented is shown in Figure 4.2.

4.3 Final Deliverables

Once the project was completed, we delivered the following materials to the client:

- Application source code
- Access to project source control
- Documentation on setup, installation, and datafile formatting
- Final project report

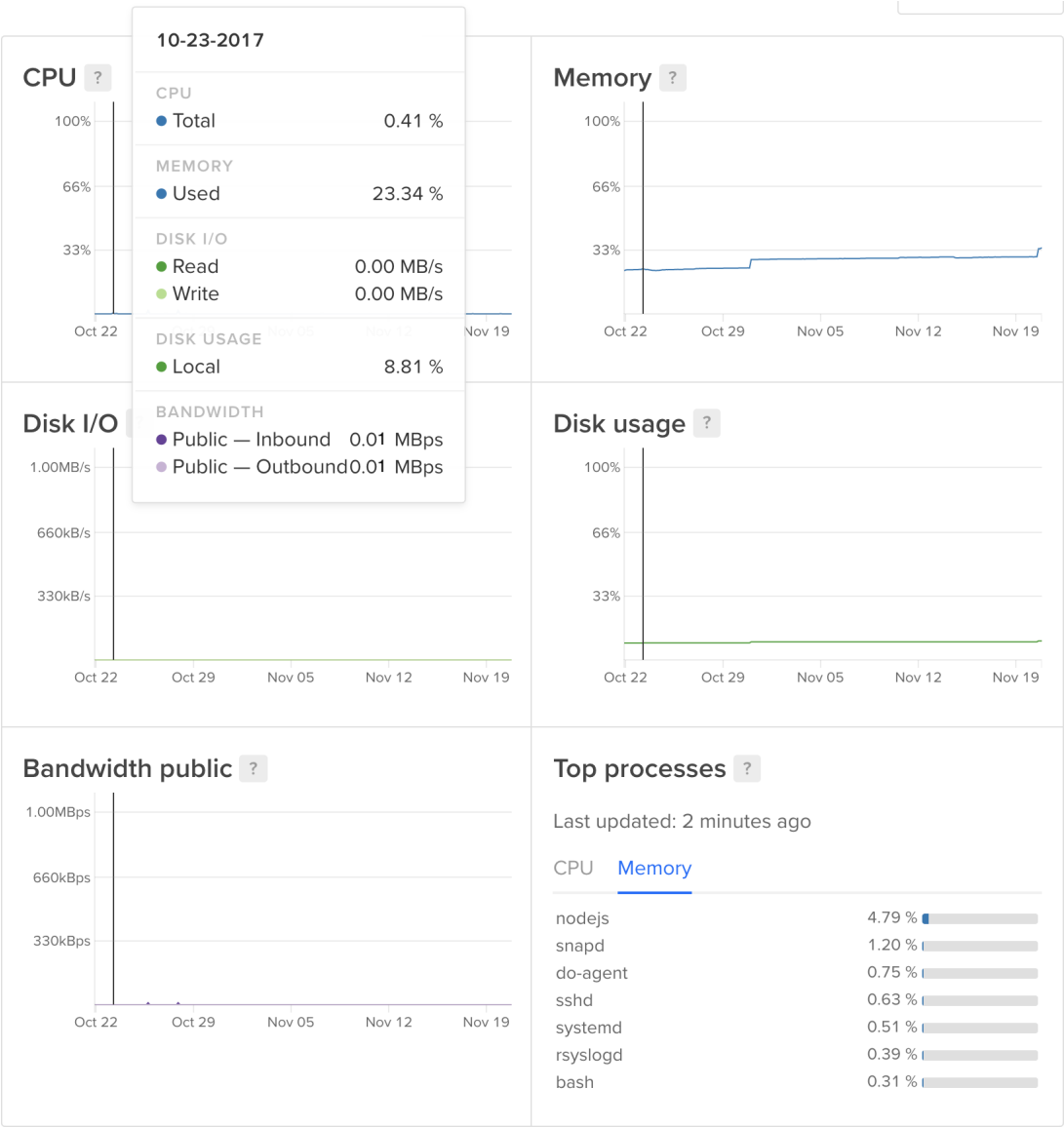


Figure 4.2: Graphs detailing the peak performance impact during user testing.

Chapter 5

Conclusion

Currently, students and professors want a well-structured and implemented framework for writing and running code in both testing and learning environments. The current widely used solutions cover most of the goals of this project in some form, shown in table 2.2, however we did not find one that met all of the goals according to our client's specifications stated in section 1.

In this thesis, we implemented a separate framework to remedy the above issues. Based on our research and testing results, our solution will help both students and teachers in many aspects of programming examinations as described in section 1. The opportunity to type and format code, along with the ability to compile and execute code is helpful to students and allows them to focus on actual test content and not trivial syntax or formatting issues. This solution also can help to dramatically cut down on the time it takes to build and grade exams due to the simple flat file format and automated grading. Therefore this solution will be of great benefit to the student as well as the professor, saving them both time and effort.

For future work we suggest adding support for other learning environment

modules such as online textbooks, and a more intuitive way of adding support for new languages. In regards to furthering security, we suggest an approach similar to the algorithm created by Chen et al. [20], which used sandboxing and regular expressions to filter out malicious code.

Appendices

.1 Environment Requirements

This project was developed on an Ubuntu 16.04.2 x64 Linux server. The following packages must be installed:

- Node (v8.9.1)
- Python (v3.5.2)
- g++-5
- Forever (Optional Node Package Manager (npm) package, used for ensuring that a given script runs continuously)

.2 System Screenshots

SAU CS

0:00

Submit Exam

Given the following declarations, evaluate the following Boolean expressions:

```
1 int x = 3, y = 5, z = 7;
```

Begin activity

When you are ready to begin, click start.

start

10

$x \geq 0 \mid\mid z < 10$
☐ True
☐ False

Suggested time: 0:00

Reset Code

<< Prev

1 | 2 3

Next >>

Figure .1: The start screen of an exam.

SAU CS

14:26

Submit Exam

In python, define and call a simple function that accepts and prints the word 'Student'.

```
1 def greet(name):  
2     print(name)  
3 greet('Student')
```

Inputs will be read in order for every line read performed. If you want to pass in an array, use this format: [int1, int2] or ["str1", "str2"].
New input: +
Current inputs: + -

Begin next section?

Once you begin this section, you will not be able to modify the previous section's answers. Do you wish to continue?

Continue Cancel

Compile

Suggested time:

4:33

Reset Code

<< Prev

1 | 2 **3**

Next >>

Figure .2: After using the compiler functionality, answers selected in the previous multiple-choice section cannot be changed.

SAU CS

13:31

View score

In python, define and call a simple function that accepts and prints the word 'Student'.

```
1 def greet(name):
2     print(name)
3     greet('Student')
```

Inputs will be read in order for every line read performed. If you want to pass in an array, use this format: [int1, int2] or ["str1", "str2"].

New input: +

Current inputs: -

Submit Exam?

Final score: 40/40, NOTE: For this exam, only one attempt can be recorded per user. These results will not be saved.

Submit Cancel

Compile

Results:
Student

Suggested time:

3:44

Reset Code

<< Prev

1 | 2 3

Next >>

Figure .3: Exam results reported back. In this case, the datafile specified not to allow multiple attempts, but did allow access. This is reported to the user in case of misunderstanding.

[\[Manage \]](#) > [\[Upload \]](#)

Format: JSON ([ex](#))

If a file is selected, all text area data on the right will be ignored.

Course ID:

Activity ID:

valid JSON datafile:

JSON with unformatted content (hard line breaks):

Format: JSON-esque ([ex](#))

Please Note:

- The 'problem' field can utilize html formatting/markup.
- If any double quotes are repeated, they must be escaped (ex: "skeleton": " cout << \"\n\"; ")
- Generally, fields should not contain hard linebreaks with the 'skeleton' field being the exception. In the skeleton field's case, the server can parse unformatted text wrapped in the following manner: '._<<_ CONTENT _>>_.' (or explicitly write /n, /t, etc. instead of linebreaks).

```
{
  "0": {
    "questionType": "mchoice",
    "language": "c++",
    "problem": "What does the following program print when the user enters the indicated values?<br /><i>NH means \"answer Not Here.\"</i>\"",
    "skeleton": "._<<_#include <iostream>
using namespace std;

int main() {
  int i, j, k;
  cin >> i >> j >> k;
  // i, j, and k are ints
  if (i < j) {
    if (j < k)
      i = j;
    else
      j = k;
  } else {
    if (j > k)
      j = i;
    else
      i = k;
  }
  cout << \"i = \" << i << \" j = \" << j << \" k = \" << k << endl;
}_>>_\",
  "input": [ [\"3 5 7\", [\"i = 3 j = 5 k = 7\", \"i = 3 j = 3 k = 7\", \"i = 5 j = 5 k = 7\", \"i = 3 j = 5 k = 5\", \"i = 3 j = 7 k = 7\", \"NH\"] ] ],
  "output": [\"0\", \"1\"],
  "points": [\"5\", \"5\"],
  "difficulty": \"0\"
},
  "prop": {
    "time": \"45\",
    "warn": [\"10\", \"5\"]
  }
}
```

Figure .4: The upload interface, showing the alternate datafile format which supports newlines.



Figure .5: A tree representing the file structure of both the exam datafiles and results, sorted by class and exam.

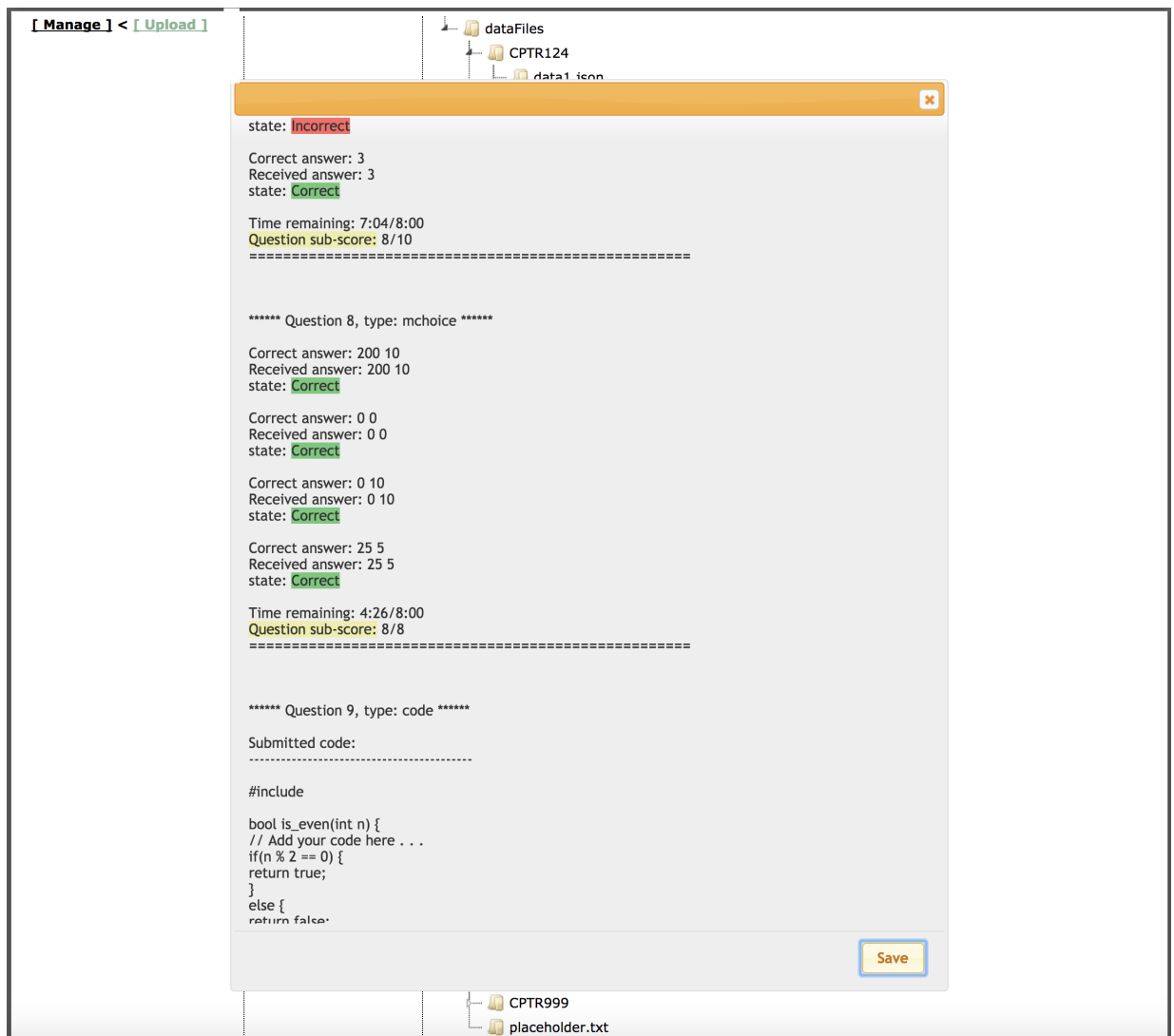


Figure .6: A styled report of all submitted results for the selected exam.

Print

Total: **125 pages**

Cancel Save

Destination Save as PDF

Change...

Pages ☒ All

☐ e.g. 1-5, 8, 11-13

Layout Portrait

+ More settings

[Print using system dialog... \(⌘P\)](#)

[Open PDF in Preview](#)

Student ID: [REDACTED]

***** Question 0, type: mcchoice *****

Correct answer: 10
Received answer: 10
state: Correct

Correct answer: 5
Received answer: 5
state: Correct

Correct answer: 93
Received answer: 93
state: Correct

Correct answer: 140
Received answer: 140
state: Correct

Time remaining: 5:20/8:00
Question sub-score: 8/8

***** Question 1, type: mcchoice *****

Correct answer: 15
Received answer: 15
state: Correct

Correct answer: 0
Received answer: 0
state: Correct

Correct answer: 4
Received answer: 4
state: Correct

Correct answer: 4
Received answer: 4
state: Correct

Time remaining: 4:43/8:00
Question sub-score: 8/8

***** Question 2, type: mcchoice *****

Correct answer: 4

<http://dhrishan.com/answadmin>

1/125

***** Question 9, type: code *****

Submitted code:

```

#include

bool is_even(int n) {
    // Add your code here . . .
    if(n % 2 == 0) {
        return true;
    }
    else {
        return false;
    }
}

```

Save

CPTR999

Figure .7: A printable exam report of all submitted results for the selected exam.

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