



Diploma thesis in the higher department of informatics

Quap - a simple quiz app

**Design, development and implementation of a
quiz and learning app**

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Frontend, Backend, Documentation, Database

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1. List of abbreviations

API:	Application Programming Interface
CI/CD:	Continuous Integration/Continuous Deployment
CLI:	Code Line Interface
CRUD:	Create, Read, Update, Delete
CSS:	Cascading Style Sheets
DBMS:	Database Management System
DOM:	Document Object Model
DTO:	Data Transfer Object
FOSS:	Free and Open Source
FTP:	File Transfer Protocol
GUI:	Graphical User Interface
HTML:	HyperText Markup Language
HTTP:	HyperText Transfer Protocol
IDE:	Integrated Development Environment
IP:	Internet Protocol
JSON:	JavaScript Object Notation
JSX:	JavaScript Extensible Markup Language (XML)
MVC:	Model View Controller
NPM:	Node Package Manager
OOP:	Object Oriented Programming
ORM:	Object Relational Mapper
OS:	Operating System
PDF:	Portable Document Format
REST:	Representational State Transfer
SQL:	Structured Query Language
UI:	User Interface
URI:	Uniform Resource Identifier
VCS:	Version Control System
VsCode:	Visual Studio Code
WYSIWYG:	What you see is what you get

2. Theoretical Foundations

This chapter delves into various applications, programming languages, frameworks, and related technologies pertinent to this work. Each component receives a thorough examination, covering its functionalities, potential use cases, unique features, benefits, drawbacks, and any existing limitations. By illuminating these strengths and weaknesses, I aim to equip readers with a comprehensive understanding of these technologies and their significance to the overall project. This section is meant as a reference point for the rest of the documentation. An explanation of what was achieved can be found in the Implementation section.

2.1. Software used

Many programs and other software were used in order to complete the must-goals. The following section will cover them in detail. To qualify as a program, a piece of software has to be executable.

2.1.1. Development

This section outlines the software used for the development of the application. The specific products were chosen for their support of the used languages as well as their ability to be installed and run on the Windows Operating System (OS). The personal preferences of the developer also played a large influence in the decision process.

2.1.1.1. Visual Studio

Visual Studio is an Integrated Development Environment (IDE) developed by the Redmond, WA-based technology company Microsoft. [1] It allows the developer to write code in multiple languages including C# and C++. It also provides tools for building and executing the written code such as compilers and tools to improve the developer experience, the most notable of which being a Debugger and several code completion tools. A debugger allows the developer to diagnose problems with the code by setting breakpoints, where the program is paused and the values of variables are shown. It also provides functionality to inform the developer when a variable changes. Visual Studio is available in 3 Versions:

- Community: Free and Open Source (FOSS) version with minimal proprietary additions; targeted towards students
- Professional: paid version; targeted towards small teams
- Enterprise: targeted towards large cooperations

The Community version was used for this project. [2]

In this project, Visual Studio was primarily used for the Backend of the application.

2.1.1.2. Visual Studio Code

Visual Studio Code (VsCode) is a code editor developed by Microsoft with a FOSS core, that also contains proprietary components such as telemetry. Although it is not a full-fledged IDE, as its core does not contain tools typically found in an IDE, such as debuggers and code completion utilities, it is still a very powerful tool thanks to its expansive and well-supported extension eco-system. It is thanks to said extensions, that VsCode has become very popular in the field of Web Development, as many developers are dependent on VsCode extensions when working with popular frameworks and libraries. When some commonly utilized tech-

nologies are used, no extensions are needed, since Microsoft has included tooling for web technologies out of the box such as a basic debugger and code highlighting for the popular programming languages JavaScript and Python [3] as well as EMMET, an extension providing productivity-enhancing abbreviations and snippets for HyperText Markup Language (HTML) and Cascading Style Sheets (CSS). [4]

In this project, Visual Studio was primarily used when developing the Frontend of the application.

2.1.1.3. Docker Desktop/Docker

Docker Desktop is a Graphical User Interface (GUI) application for Windows and macOS used to manage Docker Containers. It is available in both a FOSS community edition and a paid commercial version. It allows the developer to create and maintain Docker Images as well as Kubernetes Clusters.

Docker itself is a system that gives developers the ability to quickly deploy software. It might be easier to think of it as a way to package an application, including all dependencies and configuration files into a self-contained and reusable package. Said package is referred to as a Container. Docker is often used in combination with a Continuous Integration/Continuous Deployment (CI/CD) pipeline, where code is automatically tested, built, and in the case of Continuous Deployment published.

Images are the core of Docker. Images contain instructions on how to build Containers. Therefore, it is possible to think of them as “Blueprints” for creating Containers. The instructions are defined in a Dockerfile containing information about the Container OS, startup commands, and software dependencies. Containers themselves are instances of Docker images. As Containers are isolated and self-contained, it is possible to run multiple instances of them at the same time. This helps improve the stability and security of the deployed application.

Even if a developer does not containerize their software, as is the case with this project, Docker can still be a useful tool, because many common dependencies such as databases are available as docker images, which removes the need to install them on the development machine itself. [5]

2.1.2. Other Software

This section outlines software that was used for various miscellaneous tasks other than software development.

2.1.2.1. Mozilla Firefox

Mozilla Firefox is a FOSS Web Browser developed by the Mozilla Corporation. It began development in 1998 as a fork of the then open-source Netscape Navigator Browser, which had at one point been the most popular Web Browser in the early days of the internet. It had, however, lost a great bit of popularity at the time it was made open-source. Firefox in turn became a very popular browser in the 2000s, but it has seen declining usage for the last couple of years as the Chrome Browser, developed by Google, has taken the lead. Firefox now hovers around 3 to 10% market share depending on the region.

Firefox was used in this project to test and interact with the Frontend interface. It was preferred over Chrome or Browsers based on it, because it not only offers a greater amount of privacy but also better developer tools, especially when viewing CSS properties of HTML elements. [6]

2.1.2.2. Swagger User Interface (UI)

Swagger UI is an interface built upon the OpenAPI Specification for documenting an Application Programming Interface (API) by using either a YAML or JavaScript Object Notation (JSON) document to describe the available endpoints and the models used for data transfer. It was originally known as the Swagger Specification. Swagger itself includes a set of tools, which aid the developer in the design, development, and documentation of APIs.

Swagger UI is one of these tools. It helps the developer keep an overview of the API by generating a GUI out of the YAML/JSON document displaying all endpoints. It then allows for the testing of the endpoints by providing fields for each parameter, where test data can be entered and buttons to submit the API calls. [7]

2.1.2.3. Typst

Typst is a newly developed FOSS markup system primarily targeted toward academic use. It is intended as a replacement for LaTeX. Typst is heavily inspired by Markdown as it includes built-in syntax for commonly used text elements like bold/italic text, unordered/ordered lists, and headings. The system is entirely built with Rust, a modern type-safe high-performance programming language resulting in fast compile times compared to LaTeX.

Another major difference between Typst and older solutions is that it is not separated into a distinct markup and scripting language but is instead one language containing both capabilities. Its scripting side includes implementations of conditionals, loops, and data types including Strings, Integers, Floats, Arrays, and Dictionaries, all of which are commonly found in other programming languages making Typst very intuitive for programmers, while not being too complicated for regular users. Additionally, it supports many formats for storing bibliographies, including Hayagriva YAML and BibLaTeX files. Typst documents can be exported as Portable Document Format (PDF) and HTML files.

The markup and scripting components of Typst are very closely linked and they can both be embedded within each other. Declared variables are also shared between the two, making it very easy to for example create a list of names, programmatically modify it, and output the result in the space of a couple of lines in one file. The same procedure would require the use of multiple separate files in comparable systems. Typst also allows the user to programmatically change the properties of text elements anywhere in the document by using so-called Set Rules. The following two examples show how to add numberings to headings and how to justify the text of paragraphs:

```
set heading(numbering: "1.")

set par(
  justify: true
)
```

When used in text, programmatic elements have to be marked by writing a “#” in front of them. [8] Typst provides both a Code Line Interface (CLI) tool and a What you see is what you get (WYSIWYG) web-based editor for writing documents.

Typst allows for the creation of document-independent templates and packages. Even though Typst is still very new, there is already a thriving community of developers and general users creating said components and sharing them for free with the rest of the user base.

Typst itself is run as a startup and is headquartered in Berlin, Germany. The founders are Martin Haug and Laurenz Mäde. [9]

2.1.2.4. JabRef

JabRef is a bibliography management tool that allows the user to collect, categorize, organize, and keep track of sources. It supports searching many online repositories, the most well-known of which is Google Scholar. Additionally, it includes the functionality to extract metadata from PDF files. Collections of sources are stored as .bib BibLaTeX files, allowing them to be imported into the most common writing systems used in academia.

Sources can be categorized into several predefined categories including articles, books, thesis, and websites, each one of which requires the user to enter different information. The categories can also be edited by adding custom fields. [10] For example, this project required the addition of the date when a website was accessed.

2.1.2.5. Git/GitHub

Git is a so-called Version Control System (VCS). A VCS is an essential tool in software development. It is used to track changes made to a codebase, organize said codebase, and manage the collaboration between multiple developers in teams or open-source communities. Git was developed by Linus Torvalds, the creator of the popular FOSS OS Linux in 2005 to be a fully free and open version control standard. He created it due to the capabilities of the BitKeeper VCS, which had been used in the development of Linux, being reduced for non-paying customers.

There are a couple of concepts essential to the understanding of Git:

- **Repository:** Repositories represent the fundamental component of Git. They are used to store the code of a project or part of a project. Changes to files are also tracked on the repository level. On the technical level, it is a special database storing project revisions and history. Unlike in other similar solutions, a Git repos not only contains file data but also data about itself such as metadata and user configuration. That information is located in a “.git” directory, which is configured to be hidden. Git uses two different key structures to store data: the object store (efficiently copied during cloning) and the index (temporary and modifiable).
- **Branch:** To further segregate code changes and to avoid conflicts, where multiple developers, who are working on different features, end up overriding the work of their colleagues, Git provides the ability to create an unlimited number of branches on a repository. Upon a branch’s creation, all changes made to code only affect the branch itself and are not reflected in the rest of the repository. A branch is created as follows:

```
git checkout -b branchName  
or  
git checkout branchName  
or  
git branch branchName
```

The default branch that is initialized when creating a repository has traditionally been called “Master”. Due to negative historical denotations, the term “Main” is preferred nowadays.

- **Commit:** A commit is a snapshot of the current state of selected files in a repository. They are used by Git to record changes made to files over time. A single commit does not record the state of all files. Instead, Git looks for changes made to files by comparing the newly committed state to the previously stored one. Git then processes the changes found. All unchanged files and directories remain unaffected by the commit. A commit is the only way for a developer to change the files stored in the repository. Developers are also granted the freedom to choose which files are included in a commit. Each commit must have a descriptive message explaining the changes. Before creating a commit, files are typically staged using the `git add` command, creating a temporary list of changes to be included.
- **Merge:** If a developer is done working on a specific branch, they can integrate its changes into another branch, combining the commit history of both branches and bringing their changes together. This process is referred to as merging two (or more) branches. A branch is merged as follows:

```
git merge branchName
```

One problem that can occur when merging branches is Merge Conflicts. They occur when changes have been made to the same file in multiple branches. A developer or a team leader then has to manually inspect affected files and decide which version to keep and which to discard. One way to achieve this is to use the `git diff` command. This command is used to display changes between files. Other tools and strategies are also available to simplify conflict resolution. [11]

While it is possible to store a repository solely on a local computer, especially when working alone, it is way more common to host a repository on a server. Large organizations may have their private git servers, but there are also hosting sites, which allow users to manage repositories. The most popular option is the Microsoft-owned GitHub, which is used to host this project. In addition to simply hosting repositories, GitHub also allows users to host simple Websites and to track issues on repositories in addition to basic project management tools like a Kanban Board and CI/CD with GitHub Actions. [12]

2.2. Backend

In addition to the many programs used for completing this project, several technologies were also used as building blocks of the application. This section will cover all used in the Backend or the server of the project.

2.2.1. Programming Languages

Following section outlines which Programming Languages were used in the Backend.

2.2.1.1. C#

C#, or as it is pronounced “C sharp” is a general-purpose programming language developed at Microsoft by a team headed by the Danish software engineer Anders Heijlsberg. He was previously responsible for creating the Turbo Pascal and Delphi languages. At Microsoft, he also works on TypeScript, which will be explained later on in this document.

The language is written object-oriented, meaning that the core of each C# application is Classes, independent entities containing both variables and business logic. It also provides type safety, which in combination with the language’s automatic memory management and garbage collector makes C# very user-friendly and reliable. Its syntax is often compared to that of the very popular language Java. Microsoft originally developed the language only for their own Windows OS, but it has since been made available for macOS and Linux as well. [13] It is part of the larger .NET Framework used to create many different kinds of applications. The original .NET Framework is only supported on Windows. A cross-platform version called .NET Core is also available. The most recent .NET Core revision as of February 2024 is .NET Core 8. [14]

2.2.2. Frameworks/Libraries

In addition to C# as the main programming language of the Backend, several Frameworks, Libraries and Packages were also used in cases where additional features were required.

2.2.2.1. Asp.NET Core

Asp.NET is FOSS, cross-platform, and lightweight Framework built as an addition to the previously mentioned .NET Core Framework. It enables developers to create high-performing Web Applications with the C# language. It is based upon the older Asp.NET Framework, which opposed to its newer counterpart is only available for Windows, as it is based on the regular .NET Framework. Asp.NET still receives updates. They are, however, small in nature. Asp.NET Core is a total rewrite of the previously existing functionality.

Asp.NET Core provides the ability to create both Model View Controller (MVC) and Web API applications. MVC describes a popular architectural pattern, where the application logic is split into three distinct parts:

- **Models:** Represents the data and manages how data is stored, retrieved, and manipulated.
- **Views:** The GUI page(s) the user interacts with. They are used to display the data provided by the Models and provide interactive elements to mutate said data.
- **Controller:** A Controller acts as the middleman between the View and the Model and facilitates the transfer of data across the application.

Web APIs on the other hand merely provide endpoints, to which other applications can send and request data. They do not include graphical interfaces themselves. It is however possible to also define endpoints on MVC Controllers so that other applications also have access to the data. [15]

This project uses a Web API without any MVC Components.

2.2.2.1.1. Entity Framework Core

Asp.NET Core also provides an Object Relational Mapper (ORM) called Entity Framework Core. An ORM is an abstraction layer between the application and the database. It is used to perform Create, Read, Update, Delete (CRUD) operations, without having to write database queries by hand. They typically provide interfaces to interact with database tables as if they were regular objects. One thing of note is that the term is reserved for relational databases only. Non-relational solutions use different terms (for example Object Document Mapper in MongoDB). Entity Framework Core supports SQLServer out of the box, although there are third-party packages, which add support for further databases. [16]

2.2.2.2. AutoMapper

To convert between a Model and a Data Transfer Object (DTO), it is normally required to manually assign the values as follows:

```
#  
model.name = dto.name;  
model.date = dto.date;  
model.price = dto.price;
```

Doing this can not only lead to a lot of filler code, but it may also be impossible with larger objects. DTOs themselves will be thoroughly explained later in this document. AutoMapper is a library that allows the developer to define maps between certain models/DTOs. It will then try to automatically match corresponding fields. Should this fail, the developer is able to manually create maps as well. Maps are not bidirectional, so each one has to be created twice. AutoMapper includes an easy way of doing this by simply defining the map a second time and adding `.ReverseMap()` at the end of one of them. [17]

2.2.2.3. SignalR

In a traditional Web API, clients can only send requests to the server, to which the server may then respond. This system works well for certain use cases, but for others, for example, chats or games, it is too limited. Instead, these applications may benefit from the use of another technology, namely WebSockets. They differ from traditional HyperText Transfer Protocol (HTTP) endpoints by establishing a persistent connection between clients and servers with two-way communication channels. The technical term for communication of that sort is "Full-Duplex Communication". Messages transmitted over WebSockets are also delivered or received in real time. Although their usefulness is without doubt, WebSockets also possess certain limitations, which a developer has to keep in mind when using them:

- **Poor Security:** WebSocket messages are by default not transported securely. This may lead to unauthorized access to systems and data breaches.
- **Browser Compatibility:** Some older Browsers may not support WebSockets. Some Browsers also require other metadata or security certifications when using them.
- **Complexity:** Compared to HTTP endpoints, WebSockets are more difficult to use and implement for the developer. The developer also has to maintain the connection and manage clients, which adds even more difficulty.

As a solution to said problems, Microsoft released the SignalR library for .NET and .NET Core. It enables developers to work with WebSockets easily. At the core of SignalR are so-called Hubs. There, functions can be created, which correspond to a certain task performed by the application. Within them, business logic is defined and Model data is interacted with. Should the changes to the application state performed in a function require updates in the clients, messages can be sent to either all clients, groups of clients, or specific clients. SignalR is also very easily combined with Microsoft Identity to associate specific clients with logged-in users.

In the clients, for example, a website, SignalR is also available as a package. Once installed, event listeners can be defined, which waits for a specific message from the server. Each message requires its own listener. Additionally, clients can also call the previously discussed functions on the server by invoking them with their name and, if needed, adding data needed in the Backend.

SignalR also allows for the creation of a custom function that is executed on a client establishing a connection by overriding the `Hub.OnConnected()` or `Hub.OnConnectedAsync()` methods. It is also possible to invoke functions on the Hub on the same ASP.NET application by using a `HubContext`. Lastly, it has to be mentioned that SignalR also supports other real-time communication technologies other than WebSockets. They are, however, excluded in this documentation, since they are not used. An example of one of them would be Server Side Events. [18]

2.2.2.4. Bcrypt.NET

Bcrypt.NET is a .NET library implementing the popular Bcrypt password-hashing function. [19]

Bcrypt was designed by Niels Provos and David Mazières in 1999 and is based on the 1993 developed Blowfish Cipher, itself created by American cryptographer Bruce Schneider. Although there are newer ciphers and algorithms out there, Blowfish even has a successor called Twofish, Bcrypt is still considered secure and widely used thanks to its availability on many platforms.

It does not only just hash passwords, it also salts them. Salting adds additional security compared to just hashing, where passwords are merely encrypted using a predefined algorithm. One downside of doing things this way is that hackers retain the ability to use so-called Rainbow Tables, which are created by first gathering a list of commonly used passwords, most of them regular words without major alterations. Frequently used tricks such as replacing the letters “O” and “E” with the numbers 0 and 3 respectively are also taken into consideration. This list is then run through an algorithm to get a list of hashed passwords. Salting mitigates this issue like so: When passwords are hashed, in addition to simply applying the algorithm a random string of numbers and characters is used as a second argument to the hashing function. This string is referred to as the Salt. It is used inside of the hashing function to modify the resulting hashed password so that encrypting the same password with multiple Salts results in different outputs rendering Rainbow Tables useless.

In addition to Salts and to distinguish itself from competing solutions, Bcrypt is also significantly slower than other algorithms, making regular encryption and decryption still possible, but rendering Rainbow Tables time-consuming to produce, even without the use of Salts. [20]

2.2.3. PostgreSQL

The database used for this project is PostgreSQL, a FOSS relational database. Similar to other relational databases like MySQL and SQLServer, it stores data in tables divided into rows and columns. Another shared characteristic is that most relational databases use Structured Query Language (SQL) to write queries performing CRUD operations on stored data. What differentiates PostgreSQL from other solutions is that it is a so-called Object Relational Database, meaning that it supports concepts like custom data types and inheritance typically found in Object Oriented Programming (OOP). It also allows multiple transactions to be run at the same time, by assigning a snapshot of the database to each one and for reusable queries. [21]

This project makes use of some of these features since it uses Enums to store certain data, which are not available on other relational Database Management System (DBMS). Further details about said implementation will be covered in the Backend part of the implementation section later in this documentation. One downside of using PostgreSQL with Entity Framework Core is that it requires the installation of a third-party package called `Npgsql` to be supported.

2.2.4. Concepts

The following concepts are vital to understanding the implementation of the Backend.

2.2.4.1. REST

Representational State Transfer (REST) APIs are APIs, that use HTTP technology. The term REST itself merely describes a set of guidelines, which are recommended when designing HTTP-based APIs. They were laid out by Roy Fielding, who co-founded the Apache HTTP Server Project, in his Ph.D. thesis written in the year 2000. APIs that utilize these guidelines are called “RESTful”.

Having well-designed APIs is essential to the modern web, where developers not only work with their own APIs but also with several others hosted on other servers in the web. Therefore, it is important, that all APIs are designed similarly. The core of REST is defined by its Uniform Resource Identifier (URI) format:

URI = `scheme://authority/path[?query][#fragment]`

- **Scheme** usually denotes the protocol used (for example HTTP or File Transfer Protocol (FTP))
- **Authority** is the place, where the server is hosted (Internet Protocol (IP) Address or Domain name)
- **Path** is used to separate and organize data/pages on the server. Subsequent paths separated by slashes always indicate a hierarchical relationship
- **Query** is optional and is for example used for data entered by a user (Search parameters, ...)

- **Fragment** usually links to a specific part of data/a page (for example a heading)

Although there are several other smaller rules, six concepts build the core of REST together with the URI format. Some of these have already been alluded to previously:

1. **Client-Server:** There should always be a separation of concerns between clients (the applications processing the data) and the server (the application providing the data). Their interactions must be defined through standardized requests and responses, ensuring independence and scalability.
2. **Uniform Interface:** Resources are identified using URIs and accessed through a standard set of HTTP methods (GET, POST, PUT, DELETE). This consistency makes API usage intuitive and predictable for developers.
3. **Layered System:** This rule specifies, that it is possible for there to be middlemen, such as proxies between the client and the server as long as they are not visible to the client. They may, however, still block certain data from reaching the client. Examples would be Website-blockers on a school network.
4. **Cache:** Data should always be cachable anywhere along the network path. The responsibility to declare data as cachable is a server's job. Caching is essential to the modern web, as it massively decreases the time and cost of data transfers.
5. **Stateless:** Each separate request must include all information the server needs to be processed independently. A server should not be relied upon to have any knowledge about each client and data associated with them and it should also not store said knowledge. This improves scalability and prevents issues with server-side session management.
6. **Code-On-Demand:** Servers may transfer executable code to the client temporarily. It also has to be ensured, that the server has to make sure, that the client can execute said code. An example would be JavaScript files. [22]

2.2.4.2. DTOs

In software development, a DTO is like a specialized messenger carrying only the data needed between different parts of an application. In their implementation, DTOs look very similar to regular models. The major difference is that they are not meant to represent data stored on the database, but instead data that is sent and received. A DTO is usually associated with a model and includes all fields from said model needed for a certain data transfer. They are a good way to obfuscate data and are categorized as a Design Pattern. [23]

An example for a use-case of a DTO from this project is that when information about a specific question of a quiz is transferred to a client, any data containing information about whether or not an option is correct or not is omitted to prevent students from cheating.

2.2.4.3. Repository Pattern

The Repository pattern in ASP.NET is a design pattern, where so-called Repositories are created, that act as a middleman between Entity Framework Core and the API Controllers. All functions performing CRUD operations are defined in the Repositories, so that a Con-

troller never has to work with the database directly. The Repository pattern brings several advantages:

- **Separation of Concerns:** The repository keeps business logic decoupled from the intricate details of data access, leading to cleaner and more maintainable code. This is especially important for larger teams, where many developers work on a single codebase.
- **Reusability:** A single repository can serve multiple parts of the application, reducing code duplication and promoting consistency.
- **Flexibility:** If you need to switch data sources, you only need to modify the repository implementation, keeping the rest of the application intact. [24]

2.3. Frontend

This section will cover all technologies used in the implementation of the Frontend part of the application. The Frontend encompasses all parts of the program that a user interacts with. For example, all GUIs are part of the Frontend.

2.3.1. Programming Languages

Following Programming Languages were used in the Frontend.

2.3.1.1. JavaScript

When working on websites, developers have a limited number of technologies they can use, as most Web Browsers only support a small number fraction of what is theoretically available. Generally, only three languages are used to create websites: HTML for the markup of the general layout of the page, CSS for styling elements of a page, and JavaScript to add interactivity to a page.

Of the three, JavaScript is the only one that can be understood to be a Programming Language, although it is often referred to as a scripting language as well. In addition to common features such as Loops, Variables, and OOP, it also supports a wide variety of features specifically designed to enhance its usefulness to Web Development, as it was designed for that task. For example, it is possible to programmatically interact with elements of a HTML page by selecting them with `document.querySelector()`. It is then treated as a variable, which can be used to dynamically adjust the CSS properties of the element to modify its content. The built-in API, that provides those features is referred to as the Document Object Model (DOM) API. The name comes from the fact that a HTML document is represented as a logical tree, with each node of said tree representing an element of a page and each underlying node representing its children. [25]

2.3.1.2. TypeScript

As useful as JavaScript is to Web Development, it is also widely considered to be quite flawed. One major aspect, that is often criticized is its lack of a proper typing system. JavaScript uses so-called dynamic typing, which means that a developer does not have to specify a data type when creating a variable. This alone is not the main reason why this aspect of the language is often panned, as it is also found in other, very popular and widely praised options such as Python. The real reason is that JavaScript is very inconstant in its type-checking behavior. For example the expression `"5" == 5` checking if the right value is

the same as the left one returns true, even though the values compared are a string and a number. This is the case because in JavaScript the common “==” operator does not take into consideration the type of the values. Instead, the developer is forced to use the “===” operator. JavaScript also has so-called truthy and falsy values, where non-boolean expressions such as an empty string are interpreted as false and a non-empty string as true.

All these particularities make it very easy to make mistakes when writing JavaScript, which is often quite difficult to debug. This also makes JavaScript very unsuitable for larger projects, which is why TypeScript was developed.

TypeScript is a superset of JavaScript, which means that all valid JavaScript code is also valid TypeScript code. TypeScript main addition is static typing, meaning that it makes it possible to define the data type of a variable, although it is not strictly necessary, because TypeScript automatically tries to figure out the type of a variable on creation if initialized with a value. It also offers advanced type-checking capabilities and an improved class system. TypeScript also allows for the creation of advanced types for situations such as when an API request returns data consisting of multiple values, which should be stored together. This is achieved by using the `type` keyword. It is very similar to an interface, although it cannot directly inherit other types and it also supports many advanced typing features not found on interfaces. [26]

This project uses TypeScript as opposed to regular JavaScript.

2.3.2. Frameworks/Libraries

Common web technologies are very useful for smaller applications. As the complexity of an application grows, it becomes increasingly difficult to manage the codebase, which is why several Frameworks and Libraries were used to simplify the development process.

2.3.2.1. React

When creating larger web applications, it is very common to use the same elements more than once. For example, a website could have the feature to enable a dark mode with a toggle on every page. If developed traditionally, this toggle would have to be manually implemented on each page, which for a small element such as this might not seem like much work. However, as the application scale and the complexity increases, this approach becomes unsustainable. Imagine being tasked to implement the same complex navigation bar on multiple pages. This redundancy not only wastes development time but also creates inconsistencies and makes maintenance of the codebase harder.

There are, however, many Libraries and Frameworks that aim to solve this problem by allowing the developer to create reusable blocks called Components. The most popular solutions are Angular and React, the latter of which is used in this project. Components are self-contained, customizable, and readily interchangeable.

In the previous example, the dark mode toggle becomes a Component that, after it has been implemented once, can be used anywhere. In the case of the navigation bar, where the specific links may change, it is also possible to define the content as Props, values that can be passed to a component similarly to arguments of functions. React utilizes a virtual DOM, which is an in-memory representation of the actual DOM mentioned in the section about

JavaScript. It allows React to efficiently identify and update only the necessary parts of the UI when data changes, leading to faster and smoother user experiences. Components also make it very easy to maintain code down the line. Imagine updating the toggle behavior – you do it in one place, and the change automatically reflects across all instances.

React supports both JavaScript and TypeScript. It also allows the developer to write HTML markup directly in the JavaScript/TypeScript file using JavaScript Extensible Markup Language (XML) (JSX). [27]

2.3.2.2. Vite

One problem that occurs when working with Libraries such as React is that Web Browsers do not natively support them as they only know how to work with HTML, CSS, and JavaScript, which means that code written in React first has to be compiled to technologies understood by Browsers. This step also requires including or bundling in all dependencies required. The traditional tool of choice for this task was WebPack, but in recent years, another option, namely Vite has increased in popularity.

The main advantage of Vite is that it is much faster than WebPack. Vite achieves this by supporting ES Modules, the official module system for JavaScript. This increases efficiency because code no longer has to be bundled into a single file, which greatly reduces complexity. This makes it also possible for Vite to only update the modules for certain parts of the application since code is bundled into multiple different files. This is particularly useful for development, as it decreases reload times when making small changes to code. Vite is also able to determine if certain parts of code are really necessary to the application and then remove said code from the bundle, reducing its file size. [28]

2.3.2.3. Chakra-UI

When working with React or another Component-based Framework/Library, it soon becomes evident, that many different components occur on almost every page. A perfect example of such an element would be a Button or even something more complicated such as a Card or a Dialog/Modal. Additionally, as every Frontend developer knows, it usually takes quite a long time to decide on how the page should look and even longer to subsequently define all the necessary CSS rules.

Luckily, several packages and extensions aim to reduce the time it takes to implement standard Components and to style them. Their way of doing so varies greatly, but Chakra-UI, the solution used in this project, approaches this problem by providing the developer with several predefined and styled Components. These range from commonly used elements like the ones mentioned above to more abstract ones like one Component that is a container with the CSS flexbox display property. Chakra-UI also allows for basic styling of its Components by passing Props and it provides the functionality to easily make the website responsive (usable on smaller screens) and accessible. [29] The following shows a Button that is inside of a Container with flexbox:

```
<Flex justify="center" gap="2px" direction="row">  
  <Button colorScheme="green" p="1px">Save</Button>  
</Flex>
```

As is shown in the example given, it is very easy to work with Chakra-UI. Specific Props will not be explained here or in the following documentation of the implementation with a few exceptions.

Chakra-UI is installed using the Node Package Manager (NPM). It is then required to wrap the main Component in a ChakraProvider Component. Afterwards, Chakra-UI can be used anywhere in the application. [29]

2.3.2.4. React Router

When working on more complex projects, React alone is often not enough, since it lacks any features to declare multiple routes with different pages. There is, however, a library that adds such support called React Router. It offers several different kinds of routers. This project uses a BrowserRouter, where the current location is stored in the Browser's address bar. A BrowserRouter allows the developer to define routes and children routes by adding a path and a Component for the page like this:

```
const router = createBrowserRouter([
  {
    path: "/",
    element: <Root />,
    loader: quizLoader,
  },
  {
    path: "/editquiz/:quizId",
    element: <CreateEditQuiz />,
    loader: loader,
    action: addQuestionAction,
    children: [
      {
        path: "question/:questionId",
        element: <ShowQuestion />,
        loader: questionLoader,
      },
    ],
  },
],
```

The main Component then has to be wrapped in a Router Component in order for the routes to work.

In addition to simple routing, React Router also supports more advanced features such as loaders and actions, as shown in the example above. Loaders allow the developer to define functions that automatically get executed when the component loads. This is used to load data from an external data source (API). Actions on the other hand are more complicated. They emulate the standard HTML feature, where, when a form is submitted, a HTTP request is made. Actions intercept said request and relay the form data to a specifically defined function on a route. There, the data is processed and sent to a Backend Server. If there is only one action defined per route, said action is automatically executed on a form submit. Otherwise, the route of the action desired has to be defined on the Form.

React Router also allows for the creation of Links to redirect to another page. Redirecting is also possible as a return value of an action or via a React Hook called `useNavigate()`. [30] Hooks will be explained in the next section.

2.3.3. Concepts

The following concepts are vital to understanding the implementation of the Frontend.

2.3.3.1. React Component Types

React offers the ability to create two different types of Components: **Class** Components and **Functional** Components. Class Components are the older way, available since React was first released. They are essentially JavaScript Objects/Classes. They allow for the use of Lifecycle Methods, which perform actions at specific stages of the component's lifecycle (creation, update, deletion). They also allow for the management of the component state. This means that it is possible to store data specific to the component instance and to modify that data at any time. Functional Components, on the other hand, rely on functions for their implementation. When displayed, Functional Components act like a standard function and are executed once. They return JSX markup. Due to that behavior, they do not support Lifecycle Methods and dynamic state management. This made them by far the less popular option for a long time until Hooks were introduced. Hooks add the previously missing features to Functional Components. The by far most used Hook is the `useState` Hook. It allows for state management. It is initialized with a value and a setter function. Once the setter function is called, the entire Component gets rerendered with the updated data.

```
const [name, setName] = useState<string>("Simon")
```

In this example, the name is initialized with the value "Simon". The specification of the type is required only when working with TypeScript.

Functional Components are generally preferred nowadays since they require less Boilerplate code and are more performant. They also receive more support than Class Components, which are considered outdated at this point. Another reason for the popularity of Functional Components is that Classes behave very irregularly in JavaScript, which can lead to many bugs. Functions, on the other hand, are considered more reliable. [31]

3. Implementation

This chapter of the diploma thesis will cover the practical implementation of the project. It is divided into several chapters, where information about the architecture and code is separated into sections loosely based on the must-goals. It will also contain graphics and images, which aim to provide an even better look at the finished product.

3.1. Architecture

Even though the application is run locally, it still relies heavily on technologies commonly found in web development. A major deciding force for employing going this route was that the project is very similar to web applications in not only its concept (all available solutions, which were used as inspirations for this project are web-based) but also its general composition. The reason for this similarity is found in the fact that the application has to be accessible from not only a tutor's PC but from a student's device as well.

This sameness also extends to its general architectural Design, which like web applications is divided into a Frontend and a Backend. The former includes all Clients and GUIs accessed by students and tutors, and the latter contains a Server, which is responsible for storing and managing Quiz/Game data and for providing access to said data via multiple methods, which are outlined in Figure 1:

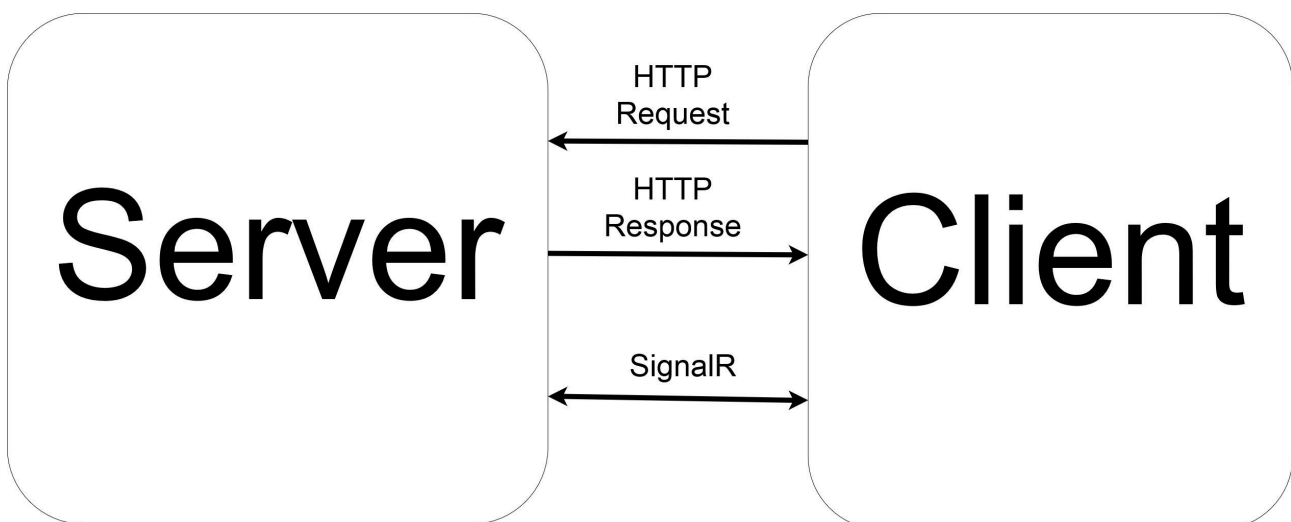


Figure 1: General Architecture Overview

As seen in the Figure 1, communication occurs both via HTTP, where data is requested by the Client and then subsequently provided/mutated/stored by the Server, as well as bidirectional SignalR WebSocket connections.

3.1.1. Backend

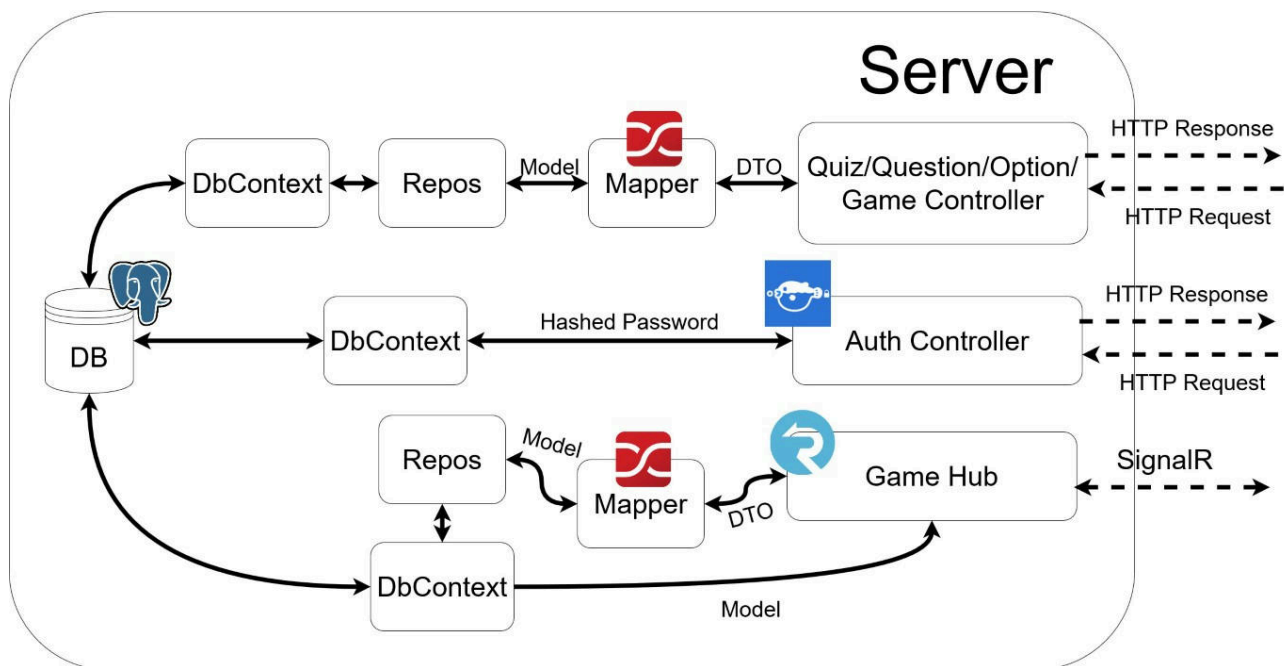


Figure 2: Backend Architecture Design

Logo Reference:

Figure 3: Postgres[32]



Figure 4: AutoMapper[33]



Figure 5: SignalR[34]



Figure 6: Bcrypt.NET[35]

Figure 2 shows the general composition of the Backend Server application. It is developed in Asp.NET Core and thus written with the C# programming language. It contains all Models, DTOs, Repositories, and Controllers needed for managing the persistent storage of Quizzes and Games in addition to basic user verification capabilities. All of these components will be explained in detail in their own sections. Information is stored in a PostgreSQL database, which is run as a Docker Container. It is initialized using a docker-compose.yaml file:

```

1 services:
2   postgres:
3     container_name: quap
4     image: postgres:latest
5     environment:
6       POSTGRES_USER: user
7       POSTGRES_PASSWORD: pwd
8     ports:
9       - 5432:5432

```

Code Snippet 1: Postgres Docker Compose

The difference between a docker-compose.yaml and a dockerfile is that the former is used to run and configure Docker Containers, while the latter is used to do the same for Docker Images. [36]. This is also evident from the code segment provided above, where an already created image providing the latest version of PostgreSQL is specified. The only thing left to

configure is the username and password for the database. Here, they are still hard-coded, as the must-goals do not require a more complex solution, but it would be better for larger projects to obfuscate that information. This, however, is outside the scope of this project.

The DbContext shown in Figure 2 is a class that utilizes Entity Framework Core. It is used to configure what to store in the database and how to do so. Further detail will follow in sections describing various Models.

3.1.2. Frontend

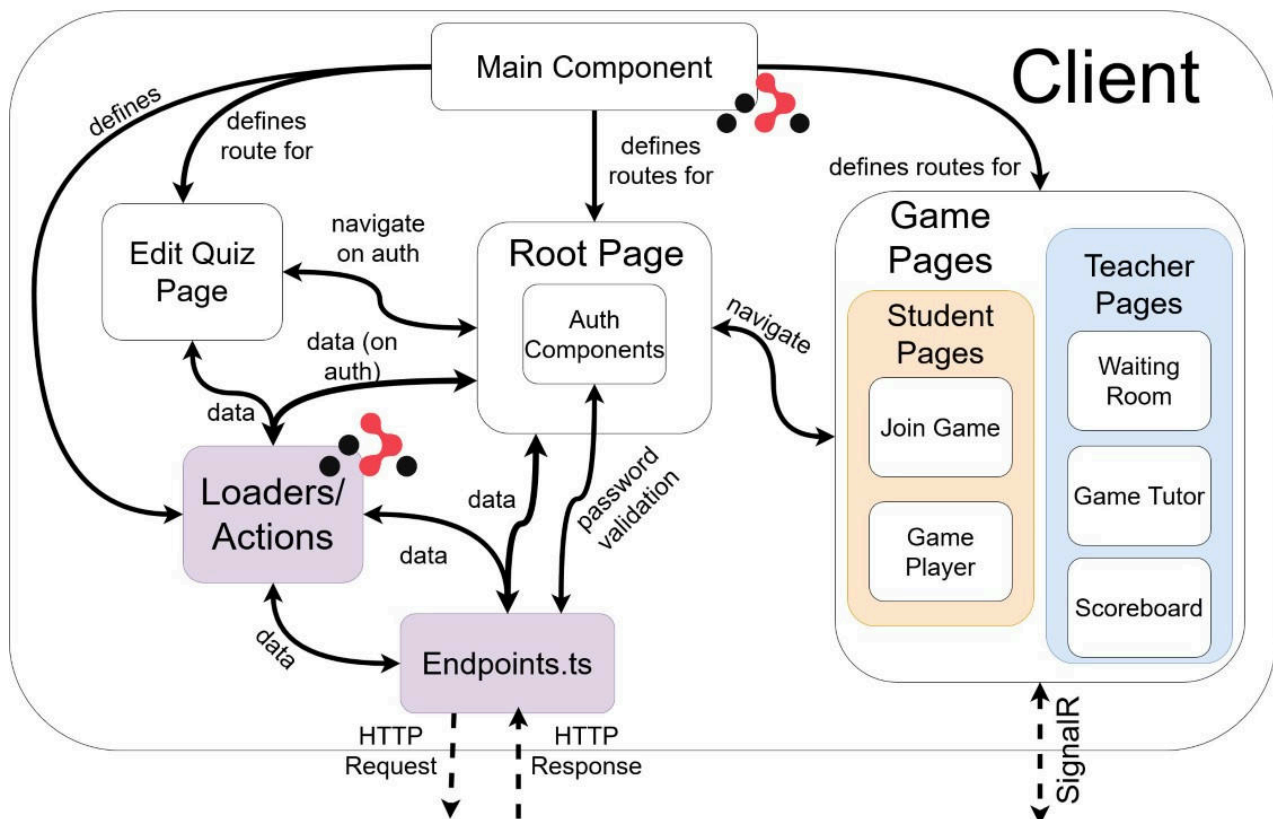


Figure 7: Frontend Architecture Design

Logo Reference:



Figure 8: React Router[37]

The Frontend of the project is a complex React application. It is divided into two main sections, which are different in both their implementation and use case. The first one is the Game Pages, which contain all the functionality needed for playing a game. They are shown in their own section in Figure 7. This part of the application mainly uses SignalR connections to communicate with the Server. The other section is the Quiz Management interfaces, entirely used by the tutor. Here, they are able to create new Quizzes, edit existing ones, or delete Quizzes, which are no longer used. These functions are separated into two pages:

- **Root Page:** Default page of the client. Displays all Quizzes and lets the tutor edit, create, delete, or start games with quizzes.

- **Edit Quiz Page:** This page is navigated when editing a Quiz. Here, individual Questions and Options are visible and editable.

Deleting and editing Quizzes requires the tutor to enter a password for verification. This segment of the Frontend relies on HTTP endpoints for interactions with the Backend, making significant use of React Router Loaders and Actions to manage data. All code needed to perform Requests to the HTTP API is located in the `endpoints.ts` file, from where it is imported into other parts of the application. All routes needed are defined in the Main Component.

3.2. Quiz Management

A major part of the planned project was a tutor's ability to manage Quizzes. This includes the creation, editing, and deleting of Quizzes and their containing Questions and Options. The aim was to create user-friendly interfaces to perform these tasks and for the Quizzes to be stored perpetually.

3.2.1. Backend

In the Server, this section includes a RESTful API providing several endpoints for managing Quizzes.

3.2.1.1. Models/DTOs

In order to properly store data, the Creation of multiple Models is required. A model is a class used as a reference by Entity Framework Core to create SQL queries to Initialize tables. Each Model represents one of these tables. This section includes three Models: Quiz, Question, and Option. Of those three, Option is the lowest in their shared hierarchical order as it is part of a Question, which in turn is part of a Quiz. The Option Model includes distinct fields that represent different essential data. The Model itself is created as a regular C# class:

```
1  public class Option
2  {
3      [Key]
4      [DatabaseGenerated(DatabaseGeneratedOption.Identity)]
5      public Guid OId { get; set; }
6      public string OptionText { get; set; } = String.Empty;
7      public bool IsCorrect { get; set; } = false;
8      public DateTime CreationDate { get; set; }
9      = DateTime.Now.ToUniversalTime();
10
11     public Guid QuestionId { get; set; }
12     public Question Question { get; set; }
13 }
```

Code Snippet 2: Option Model

The annotation `[Key]` is used to define the ID of an Option as the primary key and the line below tells Entity Framework Core to automatically generate a random ID when creating a new entry in the database. The `CreationDate` is needed for sorting Options. Note that an Option also includes a reference to the Question containing it. This is done by adding fields for the Question ID and the Question itself. This is not strictly necessary when all a developer wants to do is use a model in another model as part of a composition dependency. It is however

necessary for Entity Framework Core to properly assign foreign keys in the created database tables. Including both is considered a best practice, although it is not strictly necessary. An interesting fact was, however, discovered when testing several methods of assigning foreign keys as part of the planning stage of this project: Including both a reference to the parent object and its ID is necessary if Entity Framework Core should perform Cascading Deletes (Children of an Object are also deleted from the database when said object is deleted. This is useful since it removes the need for the developer to carefully manage the database to prevent no longer used data from being stored.). Not including any reference to the containing Model on the other hand is advantageous when Model data is referenced elsewhere or needed again at a later time. This observation was also made use of when storing Games.

As it was clear from the example given of the Option Model, Models tend to not be very complex as they simply contain definitions of fields. The Question Model is structured very similarly:

```
1 public class Question
2 {
3     [Key]
4     [DatabaseGenerated(DatabaseGeneratedOption.Identity)]
5     public Guid QuestionId { get; set; }
6     public string QuestionName { get; set; } = string.Empty;
7     public int NOptions { get; set; } = 0;
8     public List<Option> Options { get; set; } = new List<Option>();
9     public QType Type { get; set; } = QType.SingleChoice;
10    public int ?TimeLimit { get; set; }
11    public int ?Points { get; set; }
12    public DateTime CreationDate { get; set; }
13    = DateTime.Now.ToUniversalTime();
14
15    public Guid QuizId { get; set; }
16    public Quiz Quiz { get; set; }
17 }
```

Code Snippet 3: Question Model

There are, however, also several differences that deserve an examination. Line 8 shows the first example of how Models are used within other Models. It is evident from the example given that this is not very difficult to do. They can simply be used like any Class in OOP. The time limit and points are declared nullable by prefixing them with a ?. This is done because those properties are not set when creating a question and are added later. The biggest addition to the Question Model is the use of an Enum. An Enum is a set of constants, where each keyword is associated with an integer index. They are used when a variable can have multiple predefined states that can be switched between. [38]. The definition for the Question type Enum is done as follows:

```
1 public enum QType
2 {
3     SingleChoice, MultipleChoice
4 }
```

Code Snippet 4: Question type Enum

SingleChoice is assignable both with the integer: `Qtype[0]` and by using its name: `Qtype.SingleChoice`. The same goes for `MultipleChoice`. An Enum was used in this case, since it provides more flexibility if new Question types are introduced in the future and it improves the readability of the code.

The Quiz Model is structured very similarly to the Option model. It is, however, still important to the understanding of the rest of this documentation to know what is defined.

```
1 public class Quiz
2 {
3     [Key]
4     [DatabaseGenerated(DatabaseGeneratedOption.Identity)]
5     public Guid QuizId { get; set; }
6     public string Name { get; set; }
7     public string Description { get; set; }
8     public int NQuestions { get; set; } = 0;
9     public List<Question> Questions { get; set; } = new List<Question>();
10    public DateTime CreationDate { get; set; }
11    = DateTime.Now.ToUniversalTime();
12 }
```

Code Snippet 5: Quiz Model

3.2.1.2. Repositories

3.2.1.3. Controllers

3.2.2. Frontend

3.2.2.1. Main page

3.2.2.2. Edit Quiz Page

3.3. Access Control with password

3.3.1. Backend

3.3.2. Frontend

3.4. Game Flow

3.4.1. Models/DTOs

3.4.2. Repositories

3.4.3. Controller**3.4.4. Initialize Game****3.4.5. Join Game****3.4.6. Start Game****3.4.7. Gameplay****3.4.8. End Game****3.5. Miscellaneous Code****3.5.1. Configuration**

4. Conclusion

4.1. Results

4.1.1. Backend

4.1.2. Frontend

4.2. Potential future additions

4.3. Reflection on the project

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