Module Guide for Bridging Gaps: AI for Diagram Accessibility

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1 Revision History

Date	Version	Notes
November 13 2025	1.0	Rev-1 Design Document
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2 Reference Material

This section records information for easy reference.

2.1 Abbreviations and Acronyms

symbol	**description**
AC	Anticipated Change
DAG	Directed Acyclic Graph
M	Module
MG	Module Guide
OS	Operating System
R	Requirement
SC	Scientific Computing
SRS	Software Requirements Specification
Bridging Gaps: AI for Diagram Accessibility	Explanation of program name
UC	Unlikely Change
WCAG 2.1	Web Content Accessibility Guidelines
AODA	Accessibility for Ontarians with Disabilities Act
UI	User Interface
DOM	Document Object Model
AI	Artificial Intelligence
ML	Machine Learning
ARIA	Accessible Rich Internet Applications

Contents

List of Tables

List of Figures

3 Introduction

Decomposing a system into modules is a commonly accepted approach to developing software. A module is a work assignment for a programmer or programming team (Parnas et al., 1984). We advocate a decomposition based on the principle of information hiding (Parnas, 1972). This principle supports design for change, because the "secrets" that each module hides represent likely future changes. Design for change is valuable in SC, where modifications are frequent, especially during initial development as the solution space is explored.

Our design follows the rules layed out by Parnas et al. (1984), as follows:

- System details that are likely to change independently should be the secrets of separate modules.
- Each data structure is implemented in only one module.
- Any other program that requires information stored in a module's data structures must obtain it by calling access programs belonging to that module.

After completing the first stage of the design, the Software Requirements Specification (SRS), the Module Guide (MG) is developed (Parnas et al., 1984). The MG specifies the modular structure of the system and is intended to allow both designers and maintainers to easily identify the parts of the software. The potential readers of this document are as follows:

- New project members: This document can be a guide for a new project member to easily understand the overall structure and quickly find the relevant modules they are searching for.
- Maintainers: The hierarchical structure of the module guide improves the maintainers' understanding when they need to make changes to the system. It is important for a maintainer to update the relevant sections of the document after changes have been made.
- Designers: Once the module guide has been written, it can be used to check for consistency, feasibility, and flexibility. Designers can verify the system in various ways, such as consistency among modules, feasibility of the decomposition, and flexibility of the design.

The rest of the document is organized as follows. Section 4 lists the anticipated and unlikely changes of the software requirements. Section 5 summarizes the module decomposition that was constructed according to the likely changes. Section 6 specifies the connections between the software requirements and the modules. Section 7 gives a detailed description of the modules. Section 8 includes two traceability matrices. One checks the completeness of the design against the requirements provided in the SRS. The other shows the relation between anticipated changes and the modules. Section 9 describes the use relation between modules.

4 Anticipated and Unlikely Changes

This section lists possible changes to the system. According to the likeliness of the change, the possible changes are classified into two categories. Anticipated changes are listed in Section 4.1, and unlikely changes are listed in Section 4.2.

4.1 Anticipated Changes

Anticipated changes are the source of the information that is to be hidden inside the modules. Ideally, changing one of the anticipated changes will only require changing the one module that hides the associated decision. The approach adapted here is called design for change. The traceability matrix between the Anticipated (Likely) Changes and Modules is highlighted in table 17. `AC7` is mapped to multiple modules as each of these modules encapsulates the frontend subsystem and this anticipated change affects the entire frontend subsystem.

AC1: The specific infrastructure on which the software is running.

AC2: The format of the initial input data accepted by the system; in the future the system might extend to support PDFs and other formats.

AC3: The machine learning model used for alt-text generation.

AC4: The language used for alt-text generation, allowing the system to generate alt-text in multiple languages beyond English.

AC5: The duration of time the user remains authenticated before being prompted to log in again.

AC6: The range of topic domains supported for alt-text generation.

AC7: The platform that the system operates on can be extended beyond a web application to also include desktop or mobile applications.

4.2 Unlikely Changes

The module design should be as general as possible. However, a general system is more complex. Sometimes this complexity is not necessary. Fixing some design decisions at the system architecture stage can simplify the software design. If these decision should later need to be changed, then many parts of the design will potentially need to be modified. Hence, it is not intended that these decisions will be changed.

The following are changes that the system is unlikely to incur:

UC1: The project's evaluation metrics as shown in Table 5 of the Appendix in our SRS (2025) document will not change as these metrics are concrete and will be used to evaluate the effectiveness of the generated alternative text.

UC2: The primary output device for this system will remain as a screen, even if the system is later expanded to additional platforms (i.e., mobile) and not just the current web-based tool.

UC3: The system will always support keyboard input as its primary interaction method, with mouse input also supported for selecting user interface elements. This is to ensure that the functionality of keyboard navigation is always enabled for accessibility.

5 Module Hierarchy

This section provides an overview of the module design. Modules are summarized in a hierarchy decomposed by secrets in Table 2. The modules listed in Table 1 below, which are leaves in the hierarchy tree, are the modules that will actually be implemented.

AI Model Modules	**Backend Modules**	**Frontend Modules**	**System Information Modules**
DataPreprocess Module	AuthenticationService Module	UserInterfaceInteractions Module	Logging Module
WCAGCompliance Module	SessionManagement Module	MainScreen Module	
ModelOutput Module	ImageValidation Module	ShowHistoryScreen Module	
AIModelTraining Module	BackendController Module	LogInScreen Module	
CaptionGeneration Module		UserInterfaceAccessibility Module	
InternalMetricCompliance Module			
FeedbackMetrics Module			
FeedbackLoop Module			
Feedback Module			

Table 1: Module Hierarchy by Subsystem

Level 1	**Level 2**
Hardware-Hiding Module [Section (7.1)]	N/A
Behaviour-Hiding Module [Section (7.2)]	DataPreprocess Module (M1) (see 7.2.1) WCAGCompliance Module (M2) (see 7.2.2) ModelOutput Module (M3) (see 7.2.3) AuthenticationService Module (M4)(see 7.2.4) SessionManagement Module (M5) (see 7.2.10) BackendController Module (M6) (see 7.2.11) Logging Module (M7) (see 7.2.12) ImageValidation Module (M8) (see 7.2.13) UserInterfaceInteractions Module (M9) (see 7.2.5) MainScreen Module (M10) (see 7.2.6) ShowHistoryScreen Module (M11) (see 7.2.7) LogInScreen Module (M12) (see 7.2.8) UserInterfaceAccessibility Module (M13) (see 7.2.9)
Software Decision Module [Section (7.3)]	AIModelTraining Module (M14) (see 7.3.1) CaptionGeneration Module (M15) (see 7.3.2) InternalMetricCompliance (M16) (see 7.3.3) FeedbackMetrics Module (M17)(see 7.3.4) FeedbackLoop Module (M18) (see 7.3.5) Feedback Module (M19) (see 7.3.6)

Table 2: Module Hierarchy

6 Connection Between Requirements and Design

The design of the system is intended to satisfy the requirements developed in the SRS. In this stage, the system is decomposed into modules. The connection between requirements and modules is listed in Tables 3-17 in section 8.

The decompositon of the modules was separated by four main subsystems including: Frontend Modules, Backend Modules, AI Model Modules, and System Information Modules.

The front-end modules of the *Reading4All* system collectively ensure that the system meets all Look and Feel, Usability, Humanity, and Accessibility requirements through a responsive design and and clear interaction patterns. The `MainScreen`, `LogInScreen`, and

`ShowHistoryScreen` modules that are responsible for rendering the different screens of the user interface will use simple and clean layouts, WCAG-compliant contrast ratios, non-colour-dependent cues, and fully descriptive alt text for non-text elements. These display modules present only essential information and will remain intuitive to navigate. The `UserInterfaceInteractions` module will ensure usability by providing immediate textual feedback and ensure to support efficient task completion with minimal steps. Lastly, within the frontend modules, the `UserInterfaceAccessibility` module will ensure compatibility with screen readers and keyboard navigation by managing ARIA landmarks, live-region announcements, and predictable focus order. Together, these modules will deliver an interface that is simple, memorable, inclusive, and fully aligned with WCAG 2.1 Level AA and AODA standards. It will allow all users to operate the system effectively and confidently.

In the backend subsystem, many modules play a role in ensuring that the functional, performance, privacy and operational requirements specified are fulfilled. The `BackendController Module` coordinates the flow of data between the Frontend, AI modules and other Backend modules. It ensures that user's and their inputs are validated, and alternative text is generated by invoking the appropriate modules. The `BackendController` also ensures that users are presented with the appropriate information and never exposed to technical details. The `ImageValidation` module fulfills the requirements relating to validating user inputs. This module checks that inputted images are of the correct size and types before the alt text generation process begins. The `Logging` module records any system events and errors, helping fulfill requirements related to protecting user data and having a reliable system. The `Logging` module will help ensure that user data is always deleted when any system failure occurs.

Furthermore, within the backend subsystem, the `AuthenticationService` and `SessionManagement` modules together ensure secure and reliable user interaction with the Reading4All platform. The `AuthenticationService` module is responsible for verifying user credentials, issuing secure tokens, and validating user identity before granting access to system functionalities. It guarantees that only authenticated users can upload images or retrieve generated alt text, fulfilling the security and privacy requirements defined in the SRS. Supporting this, the `SessionManagement` module manages each user's active session lifecycle by creating, validating, refreshing, and terminating session tokens. It also maintains a short-term record of user interactions during the active session, such as image uploads and model outputs, ensuring that users can view their recent activity while preserving system integrity and confidentiality. Together, these two backend modules ensure that all authentication, authorization, and session tracking processes are handled transparently and securely, thereby supporting reliability, data protection, and user trust across the Reading4All system.

7 Module Decomposition

Modules are decomposed according to the principle of "information hiding" proposed by Parnas et al. (1984). The *Secrets* field in a module decomposition is a brief statement of the design decision hidden by the module. The *Services* field specifies *what* the module will do without documenting *how* to do it. For each module, a suggestion for the implementing software is given under the *Implemented By* title. If the entry is *OS*, this means that the module is provided by the operating system or by standard programming language libraries. *Bridging Gaps: AI for Diagram Accessibility* means the module will be implemented by the Bridging Gaps: AI for Diagram Accessibility software.

Only the leaf modules in the hierarchy have to be implemented. If a dash (–) is shown, this means that the module is not a leaf and will not have to be implemented.

7.1 Hardware Hiding Modules

This subsection is N/A as the Reading4All system has no hardware components.

7.2 Behaviour-Hiding Modules

This subsection includes modules that pertain to the required behavior of the Reading4All system. The modules are defined as their own subsection and follow the following format:

Secrets: This part describes the essential behavioral components that define a module's intended functionality.

Services: This component defines the module's programs that implement the externally visible behaviors of the system, as outlined in the Software Requirements Specification (SRS). Any modifications to the SRS will likely require corresponding updates to the programs within this module.

Implemented By: This part mentions if the Reading4All system or external systems will implement the specific module.

Type of Module: This section defines the module type into a Record, Library, Abstract Object, or Abstract Data Type. This section also includes information for leaf modules in the decomposition by secrets tree.

7.2.1 DataPreprocess Module (M1)

Secrets: Includes the steps used to prepare input images for further processing.

Services: Normalizes, sorts, and standardizes the image input so it can be correctly used by the training and caption generation modules.

Implemented By: Reading4All

Type of Module: Library

7.2.2 WCAGCompliance Module (M2)

Secrets: The rules used to decide whether a caption meets AODA (Ontario (2005)) and WCAG 2.1 AA accessibility standards (W3C (2018)).

Services: Checks the generated text against WCAG 2.1 AA (W3C (2018)) criteria and flags or adjusts any generated alt text that does not meet these standards.

Implemented By: Reading4All

Type of Module: Library

7.2.3 ModelOutput Module (M3)

Secrets: The structure used to store and present the final text to the user via the Backend-Controller as mentioned in Section 7.2.11.

Services: Produces and formats the final version of the accessibility-compliant text for output or download.

Implemented By: Reading4All

Type of Module: Record

7.2.4 AuthenticationService Module (M4)

Secrets: The internal logic for credential verification, token structure and signing, token refresh rules, lockout thresholds, and interactions with external authentication providers. Includes error classification for authentication failures and audit-safe handling of sensitive data.

Services: Verifies user credentials, issues and refreshes authentication tokens, validates tokens on incoming requests, resolves current user identity (userID/role) for access control. This module is used to sign up new users, log in existing users. This is also used to protect user data and ensure only necessary sign up information is collected and stored.

Implemented By: Reading4All

Type of Module: Library

7.2.5 UserInterfaceInteractions Module (M9)

Secrets: The internal logic and mapping of user-triggered actions such as clicks and keyboard presses on the user interface into the backend and display screens modules.

Services: Captures user actions from the UI and connects UI controls to application behavior by attaching event handlers that calls on other modules' access programs with validated parameters.

Implemented By: Reading4All Team

Type of Module: Library

7.2.6 MainScreen Module (M10)

Secrets: The internal layout composition of the main screen. This includes how the upload panel and supporting UI elements are arranged and rendered into the `DOM`.

Services: Renders the "Main" screen of the application. This screen displays the image-upload entry point for users. It calls on the UserInterfaceAccessibility module to assign the main landmark, set initial focus, and announce the screen to screen readers.

Implemented By: Reading4All Team

Type of Module: Library

7.2.7 ShowHistoryScreen Module (M11)

Secrets: The internal layout composition of the show history screen when an authenticated user wants to see their previously generated alt-text history. This includes how the history items are formatted and displayed.

Services: Renders the user's current session history to the screen. It relies on the UserInterfaceAccessibility module to set the main landmark, focus the first history item (if any), and announce the screen.

Implemented By: Reading4All Team

Type of Module: Library

7.2.8 LogInScreen Module (M12)

Secrets: The internal layout composition of the log in screen including username/email and password fields, and a log in button.

Services: Renders the system's Log In screen. It calls on the UserInterfaceAccessibility module to set focus on the fields on the log in form and announce the screen.

Implemented By: Reading4All Team

Type of Module: Library

7.2.9 UserInterfaceAccessibility Module (M13)

Secrets: The internal mechanism for providing screen reader and keyboard navigation compatibility in the browser. This includes how ARIA (W3C (2024)) live regions are implemented, how focus is manipulated, and how keyboard navigation is enabled internally.

Services: Provides accessibility capabilities to other user interface modules by: assigning and maintaining the correct main landmark on each screen; managing which element receives initial keyboard focus; sending announcements to screen readers using ARIA (W3C (2024)) live regions; and enabling keyboard navigation patterns.

Implemented By: Reading4All Team

Type of Module: Library

7.2.10 SessionManagement Module

Secrets: The representation and storage of active sessions, expiry/refresh policies, session-history data structures (interaction entries and Reading4All data references), and eviction/cleanup strategies. Includes indexing strategies for fast token lookups and privacy rules for session-scoped logs.

Services: Creates, validates, refreshes, and deletes sessions; appends interaction entries; links session activity to Reading4All data records; retrieves filtered session history and recent data references for the current session.

Implemented By: Reading4All

Type of Module: Abstract Data Type

7.2.11 BackendController Module (M6)

Secrets: The internal application flow of data and user inputs, including how backend requests are processed and routed between services.

Services: Coordinates backend responses by receiving requests from the frontend and directing it to the appropriate service such as the User Authentication or AI Model, and returning the results.

Implemented By: Reading4All

Type of Module: Library

7.2.12 Logging Module (M7)

Secrets: The internal details of which events and errors are logged and the specific format used for log entries.

Services: Records system events and errors received from the BackendController Module.

Implemented By: Reading4All

Type of Module: Library

7.2.13 ImageValidation Module (M8)

Secrets: The internal details of how uploaded images are verified, including how file type/size are checked and whether a file is reachable.

Services: Validates uploaded images to ensure that they meet system requirements before the alt text generation process.

Implemented By: Reading4All

Type of Module: Library

7.3 Software Decision Modules

This subsection includes the modules' internal operations, connections with other modules and decision making components. Similar to Section 7.2 the modules are defined as their own subsection and follow the following format:

Secrets: Internal logic, data flow, and processing steps that define how the system produces and improves alternative text.

Services: Implements the internal operations of the system, such as model training, caption generation, quality validation, feedback collection, and output production.

Implemented By: This part mentions if the Reading4All system or external systems will implement the specific module.

Type of Module: This section defines the module type into a Record, Library, Abstract Object, or Abstract Data Type. This section also includes information for leaf modules in the decomposition by secrets tree.

7.3.1 AIModelTraining Module (M14)

Secrets: The internal design of how the model is built and improved. This includes how image and text data are linked, how training is divided into sets, and what hidden patterns the model learns. The specific model structure and training process are not exposed to other modules.

Services: Trains the system to understand relationships between images and text so it can later describe new images accurately. Produces a trained model and supporting data (such as validation results) that are used by the CaptionGeneration module.

Implemented By: Reading4All

Type of Module: Abstract Object

7.3.2 CaptionGeneration Module (M15)

Secrets: The process the system uses to generate descriptive text from an image. This includes how image features are interpreted and how words are selected and arranged into sentences.

Services: Uses the trained model from the AIModelTraining module to produce alternative text for a given image. Passes the generated caption to the WCAG (W3C (2018)) and InternalMetricCompliance modules to ensure it meets accessibility and clarity standards.

Implemented By: Reading4All

Type of Module: Library

7.3.3 InternalMetricCompliance Module (M16)

Secrets: The internal measures chosen by Team 22 to judge how clear, concise or relevant the generated text is.

Services: Reviews each caption using internal quality checks that complement the AODA (Ontario (2005)) and WCAG 2.1 AA (W3C (2018)) validation standards.

Implemented By: Reading4All

Type of Module: Library

7.3.4 FeedbackMetrics Module (M17)

Secrets: How user feedback is collected, interpreted, and organized for later use in model improvement. The exact method for analyzing or weighting different types of feedback is hidden.

Services: Receives direct input from users in the form of comments, ratings, or corrections about the generated alternative text. Summarizes this information into a structured format that can be used to guide model retraining and future system updates.

Implemented By: Reading4All

Type of Module: Library

7.3.5 FeedbackLoop Module (M18)

Secrets: The rules and internal logic that determine how user feedback is used to update and improve the system's model. The specific approach to retraining or fine-tuning is hidden.

Services: Takes processed feedback data from the FeedbackMetrics module and uses it to retrain or adjust the model over time. This allows the system to gradually improve its accuracy and produce captions that better reflect user expectations.

Implemented By: Reading4All

Type of Module: Abstract Data Type

7.3.6 Feedback Module (M19)

Secrets: How feedback information is stored and organized.

Services: Stores the user's feedback entries and makes them available to the FeedbackMetrics and FeedbackLoop modules for review and improvement purposes.

Implemented By: Reading4All

Type of Module: Record

8 Traceability Matrix

This section shows below how different requirements connect to our modules. This can be seen in Table 3, Table 4, Table 4, Table 5, Table 6, Table 7, Table 8, Table 9, Table 10, Table 11, Table 12, Table 13, Table 14, Table 15, Table 16.

Finally, Table 17 shows how our modules connect to the anticipated changes two traceability matrices: between the modules and the requirements and between the modules and the anticipated changes.

Req.	**Modules**
FR1	M1, M6, M8
FR2	M6, M15, M17, M18, M19
FR3	M2, M3, M6, M13
FR4	M6
FR5	M5, M6, M11
FR6	M4, M6

Table 3: Trace Between Functional Requirements and Modules

Req.	**Modules**
LFR-AR1	M9, M10, M11, M12, M13
LFR-AR2	M10, M9, M11, M12, M13
LFR-AR3	M10, M9, M11, M12, M13
LFR-AR4	M16, M10, M9, M11, M12. M13

Table 4: Trace Between Look and Feel Requirements and Modules

Req.	**Modules**
LFR-SR1	M9, M10, M11, M12, M13
LFR-SR2	M9, M10, M11, M12, M13
LFR-SR3	M9, M10, M11, M12, M13

Table 5: Trace Between Style Requirements and Modules

Req.	**Modules**
UHR-EUR1	M2, M3, M9, M10, M11, M12. M13
UHR-EUR2	M9, M10, M11, M12, M13
UHR-EUR3	M9, M10, M11, M12, M13
UHR-EUR4	M9, M10, M11, M12, M13

Table 6: Trace Between Usability and Humanity Requirements and Modules

Req.	**Modules**
UHR-PIR1	M9, M10, M13

Table 7: Trace Between Personalization and Internationalization Requirements and Modules

Req.	**Modules**
UHR-LR1	M9, M10, M11, M12, M13

Table 8: Trace Between Learning Requirements and Modules

Req.	**Modules**
UHR-UPR1	M9, M10, M11, M12, M13

Table 9: Trace Between Understandability and Politeness Requirements and Modules

Req.	**Modules**
UHR-AR1	M9, M10, M11, M12, M13
UHR-AR2	M9, M10, M11, M12, M13

Table 10: Trace Between Accessibility Requirements and Modules

Req.	**Modules**
PR-SL1	M15
PR-SL2	M13
PR-SCR1	M5
PR-SCR2	M16
PR-SCR3	M9, M10, M11, M12, M13
PR-SR-HA1	M6, M7, M5, M4
PR-SR-HA2	M6, M7
PR-SR-HA3	M6, M8
PR-PAR1	M15
PR-PAR2	M16
PR-PAR3	M17
PR-RFT1	M8, M6, M7
PR-RFT2	M6, M7
PR-CR1	M5, M4, M6, M7
PR-CR2	M4, M11
PR-SER1	M14
PR-LR1	M14, M2
PR-LR2	M9, M10, M11, M12, M13

Table 11: Trace Between Performance Requirements and Modules

Req.	Modules
OER-EP1	M1, M2, M3, M4, M5, M6, M7, M8, M9, M10, M11, M12, M13, M14, M15, M16, M17, M18, M19
OER-EP2	M9
OER-WE1	M2
OER-WE2	M1, M2, M3, M4, M5, M6, M7, M8, M9, M10, M11, M12, M13, M14, M15, M16, M17, M18, M19
OER-IAS1	M1
OER-IAS2	M8
OER-IAS3	M16
OER-PR1	M1, M2, M3, M4, M5, M6, M7, M8, M9, M10, M11, M12, M13, M14, M15, M16, M17, M18, M19
OER-RL1	M1, M14, M15, M2, M16
OER-RL2	M1, M2, M3, M4, M5, M6, M7, M8, M9, M10, M11, M12, M13, M14, M15, M16, M17, M18, M19

Table 12: Trace Between Operational and Environmental Requirements and Modules

Req.	Modules
MS-MNT1	M1, M15, M2, M9, M10, M11, M12, M13, M6
MS-MNT2	M1, M2, M3, M4, M5, M6, M7, M8, M9, M10, M11, M12, M13, M14, M15, M16, M17, M18, M19
MS-MNT3	M1, M2, M3, M4, M5, M6, M7, M8, M9, M10, M11, M12, M13, M14, M15, M16, M17, M18, M19
MS-SUP1	M7
MS-AD1	M14
MS-AD2	M5,M6, M7
MS-AD3	M1, M2, M3, M4, M5, M6, M7, M8, M9, M10, M11, M12, M13, M14, M15, M16, M17, M18, M19

Table 13: Trace Between Maintainability and Support Requirements and Modules

Req.	**Modules**
SR-AR1	M6, M4
SR-AR2	M6, M5
SR-IR1	M6
SR-IR2	M6, M1
SR-PR1	M6
SR-PR2	M16
SR-AU1	M7
SR-AU2	M7
SR-IM1	M8
SR-IM2	M4

Table 14: Trace Between all Security Requirements and Modules

Req.	**Modules**
CR1	M15
CR2	M16
CR3	M16

Table 15: Trace Between all Cultural Requirements and Modules

Req.	**Modules**
CR-LR1	M2
CR-SCR1	M6
CR-SCR2	M7

Table 16: Trace Between all Compliance Requirements and Modules

AC	**Modules**
AC1	M6
AC2	M8
AC3	M14
AC4	M3
AC5	M5
AC6	M15
AC7	M9, M10, M11, M12, M13

Table 17: Trace Between Anticipated Changes and Modules

9 Use Hierarchy Between Modules

In this section, the uses hierarchy between modules is provided. Parnas (1978) said of two programs A and B that A *uses* B if correct execution of B may be necessary for A to complete the task described in its specification. That is, A *uses* B if there exist situations in which the correct functioning of A depends upon the availability of a correct implementation of B. Figure 1 illustrates the use relation between the modules. It can be seen that the graph is a directed acyclic graph (DAG). Each level of the hierarchy offers a testable and usable subset of the system, and modules in the higher level of the hierarchy are essentially simpler because they use modules from the lower levels.

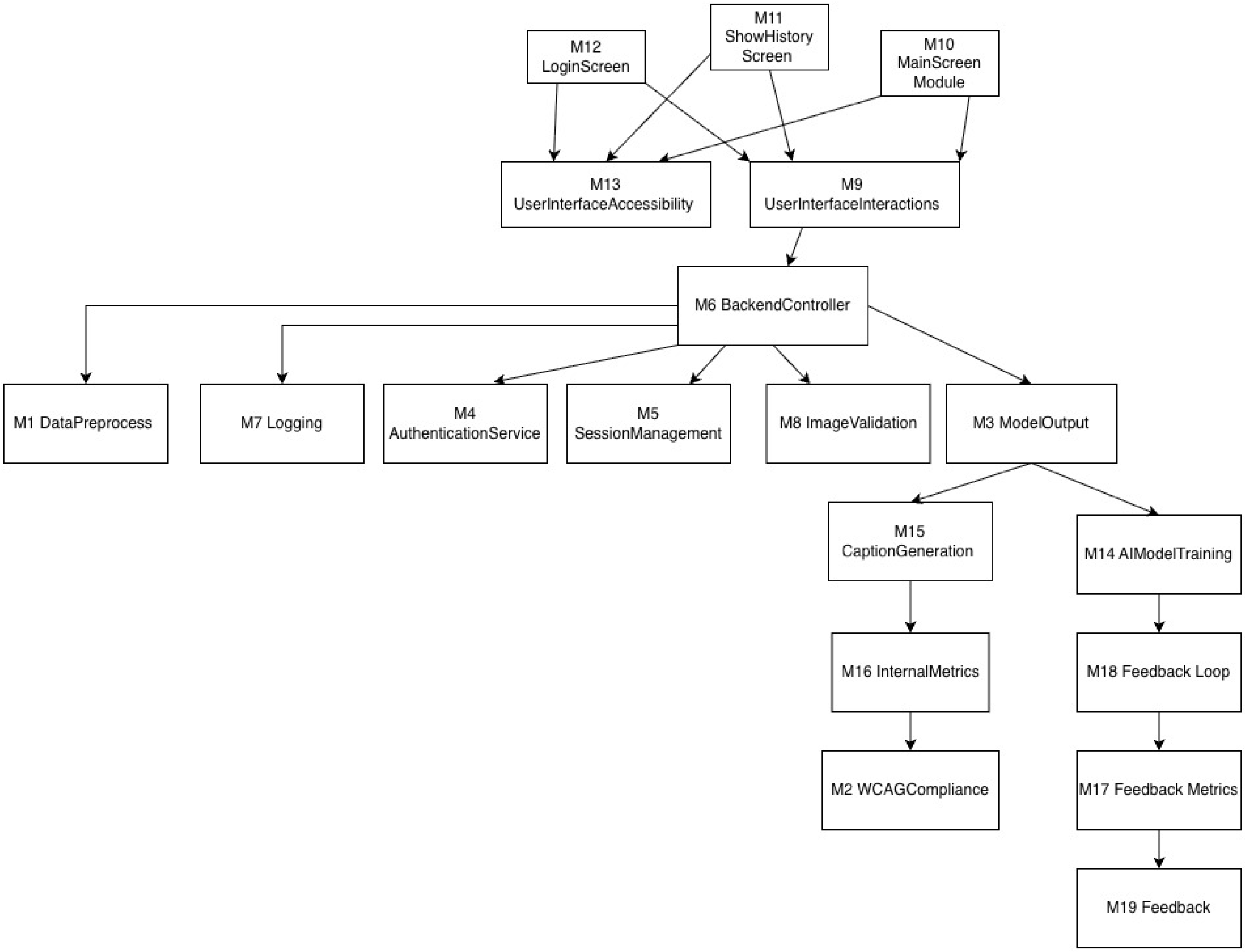
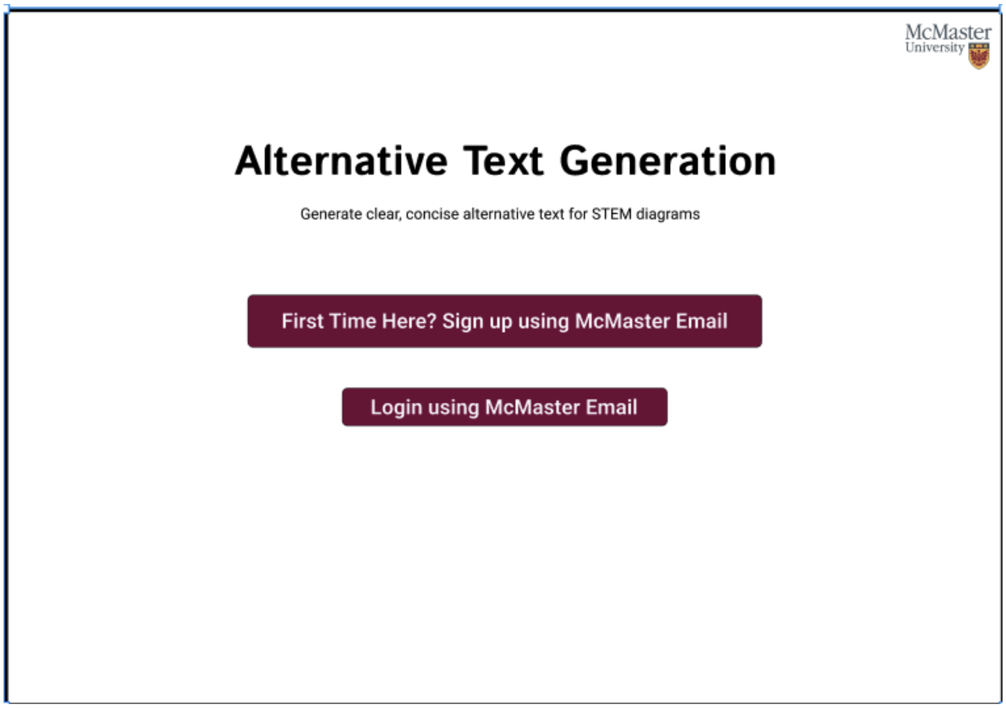


Figure 1: Use hierarchy among modules

10 User Interfaces

The *Reading4All* interface is composed of multiple pages. The home page, shown in Figure 2, serves as the primary entry point to the *Reading4All* system. From this interface, users are introduced to the purpose of the application and are provided with clear navigation options to either sign up for a new account or log in to an existing one. The home page is designed to be minimal and accessible, ensuring that users can quickly understand the system's functionality and proceed to authentication without unnecessary complexity. The sign-up page, shown in Figure 3, allows new users to create an account by providing the required registration information. Upon submission, the system validates the provided details and directs the user to either a sign-up success page (Figure 4) or a sign-up failure page (Figure 5), clearly indicating whether the account creation process was successful. The login page enables returning users to authenticate using their existing credentials. As shown in Figures 6 and 7, the system provides explicit feedback by redirecting users to either a login success page upon successful authentication or a failure page when invalid credentials are detected. The user is able to upload their images of diagrams through the interface shown in Figure 8. Furthermore, the system directs the user to a success or failure page accordingly, as highlighted Figure 9 and Figure 10, respectively. Once the user has successfully uploaded an image, they can initiate the alt text generation process by selecting the button seen in Figure 9. Finally, the user is presented their generated alt text and an option to copy it, as shown in Figure 11. Moreover, the user is able to view their history and sign out at any time through the top bar of each page. The history page allows users to view their 10 latest alt text generations and can be seen in Figure 12.

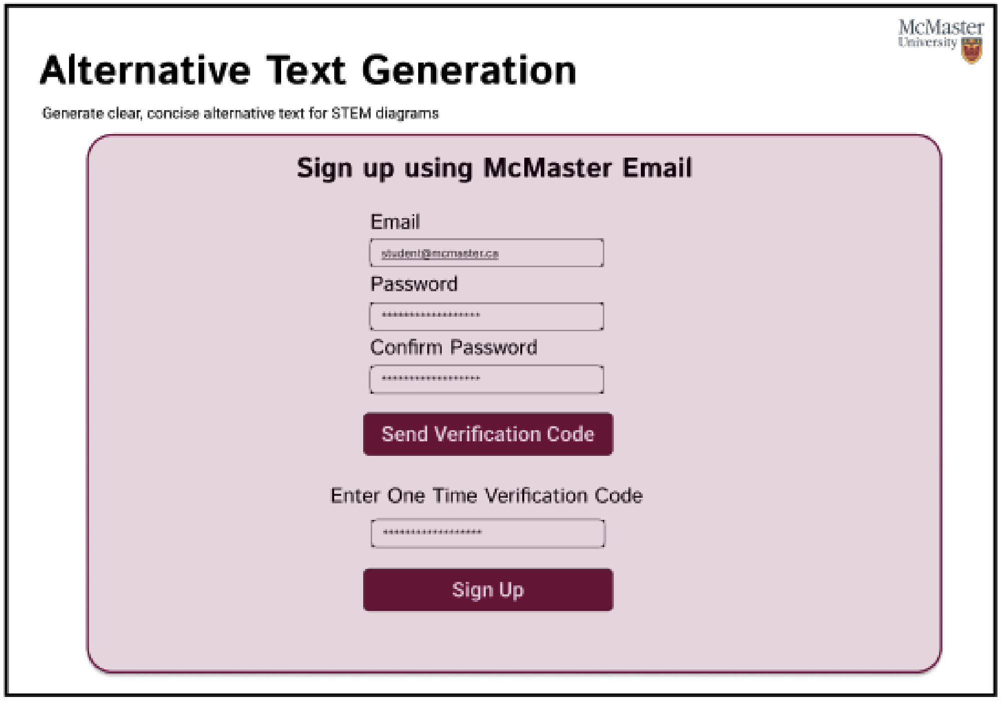


Alternative Text Generation

Generate clear, concise alternative text for STEM diagrams

McMaster University
First Time Here? Sign up using McMaster Email
Login using McMaster Email

Figure 2: Home Page UI



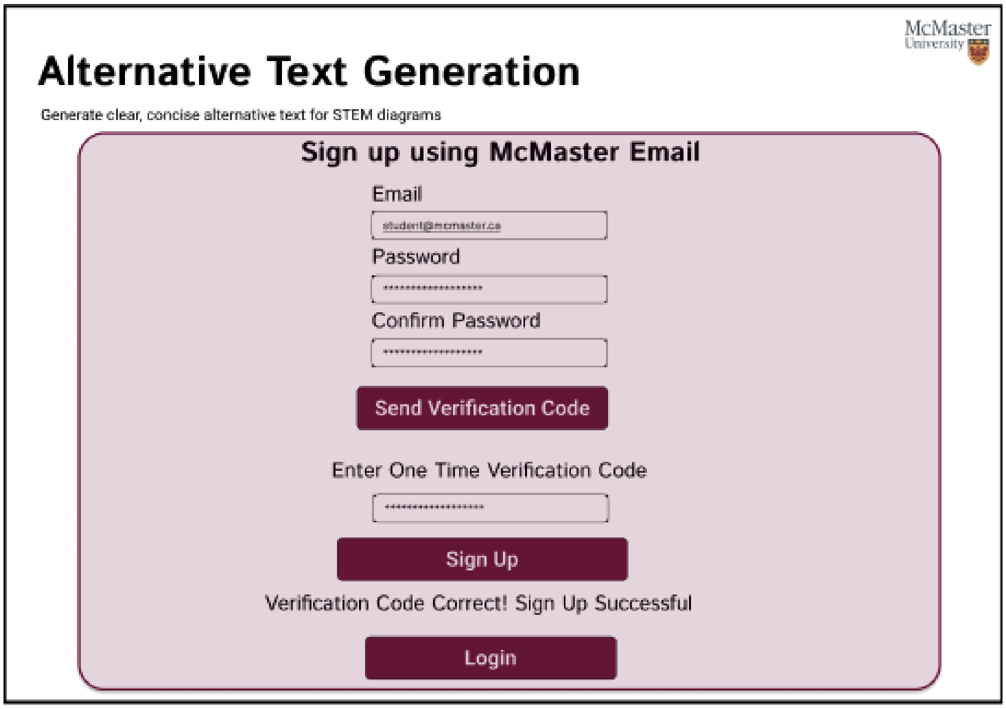
Alternative Text Generation

Generate clear, concise alternative text for STEM diagrams

Sign up using McMaster Email

Email: student@mcmaster.ca

Figure 3: Sign Up Page UI



Alternative Text Generation

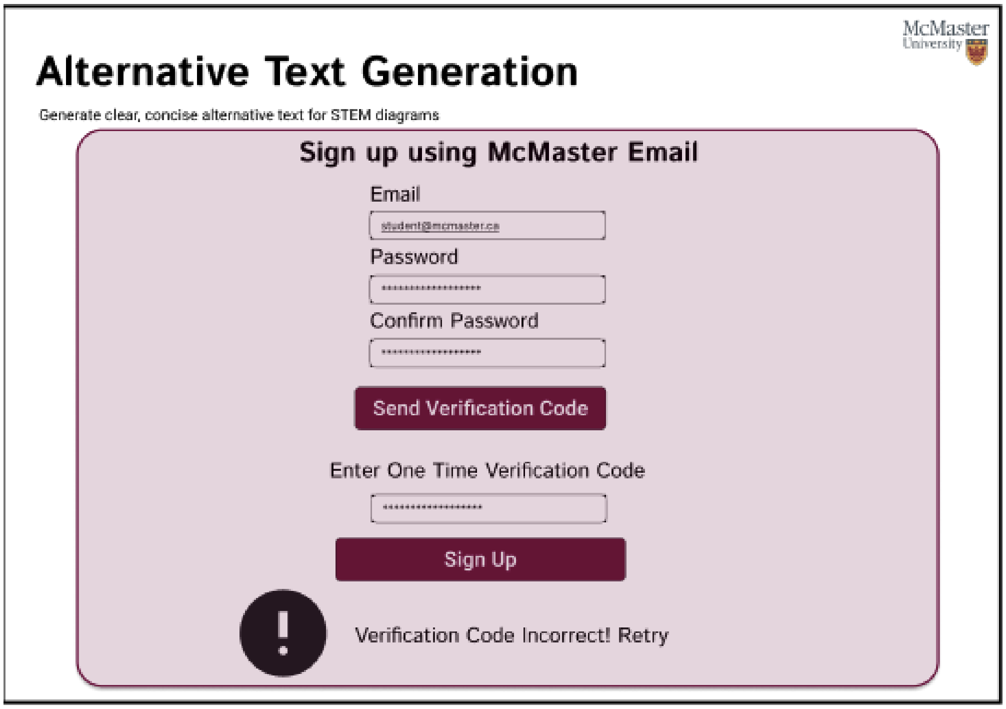
Generate clear, concise alternative text for STEM diagrams

Sign up using McMaster Email

Email: student@mcmaster.ca

Verification Code Correct! Sign Up Successful

Figure 4: Sign Up Success Page UI



Alternative Text Generation

Generate clear, concise alternative text for STEM diagrams

Sign up using McMaster Email

Email: student@mcmaster.ca

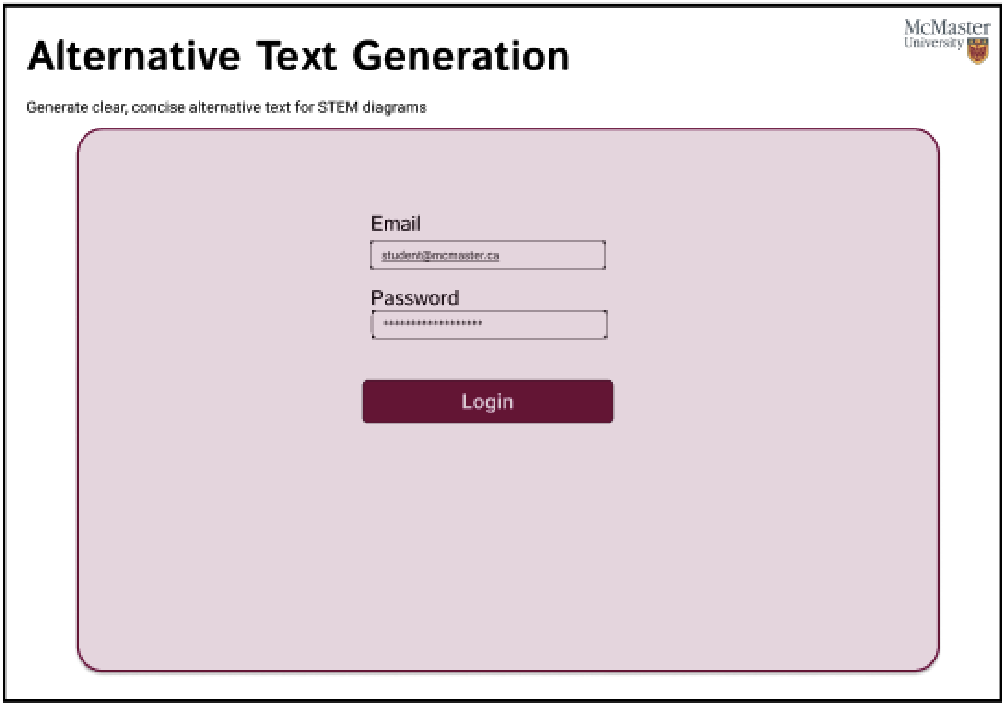
Password: ******************

Confirm Password: ******************

Enter One Time Verification Code: ******************

Verification Code Incorrect! Retry

Figure 5: Sign Up Failure Page UI



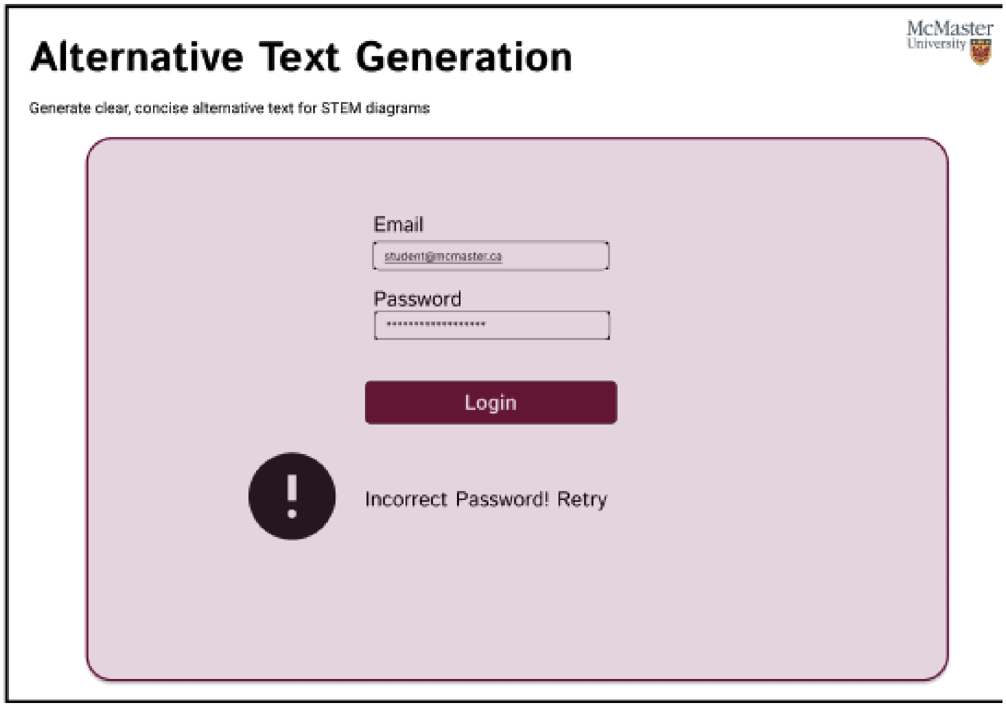
Alternative Text Generation

Generate clear, concise alternative text for STEM diagrams

Email: student@mcmaster.ca

Password: ******************

Figure 6: Login Page Success UI



Alternative Text Generation

Generate clear, concise alternative text for STEM diagrams

Email

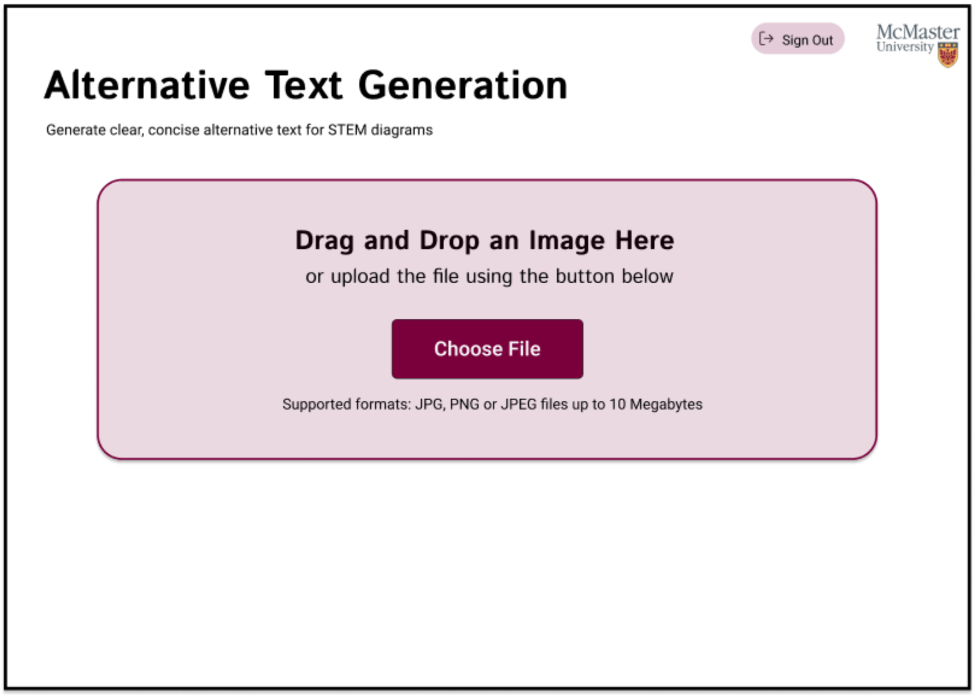
student@mcmaster.ca

Password

****

Incorrect Password! Retry

Figure 7: Login Page Failure UI



Alternative Text Generation

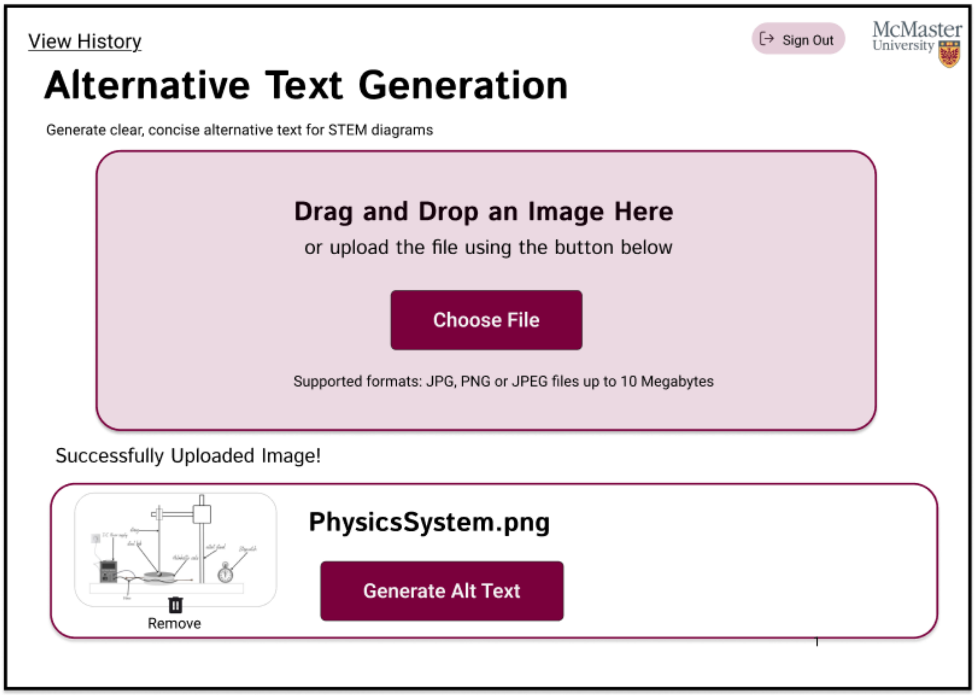
Generate clear, concise alternative text for STEM diagrams

Drag and Drop an Image Here

or upload the file using the button below

Supported formats: JPG, PNG or JPEG files up to 10 Megabytes

Figure 8: Upload Page UI



Alternative Text Generation

Generate clear, concise alternative text for STEM diagrams

Drag and Drop an Image Here

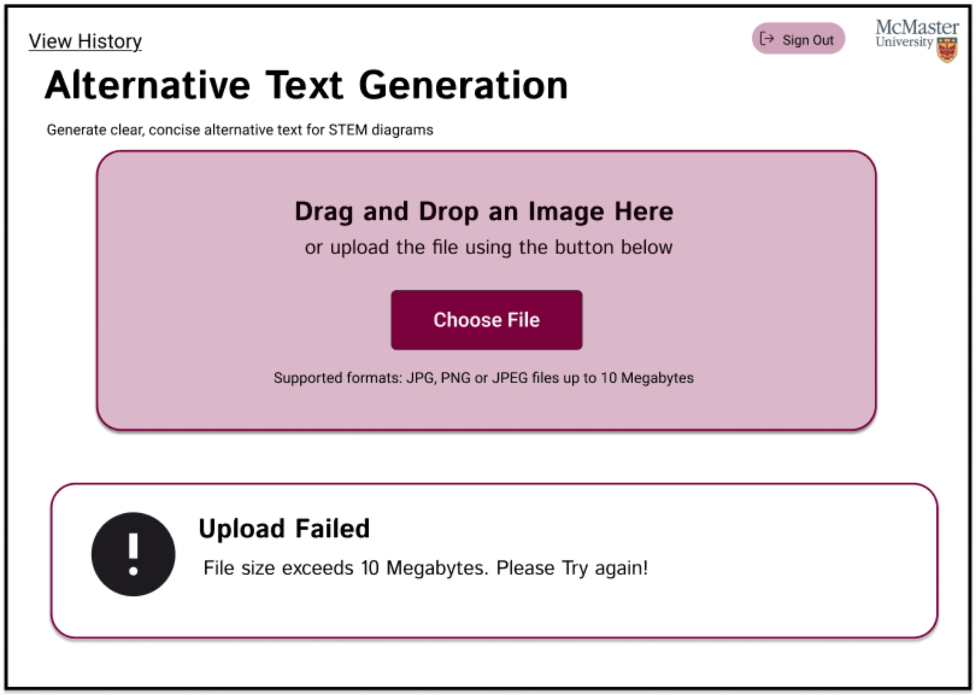
or upload the file using the button below

Supported formats: JPG, PNG or JPEG files up to 10 Megabytes

Successfully Uploaded Image!

PhysicsSystem.png

Figure 9: Upload Success UI



Alternative Text Generation

Generate clear, concise alternative text for STEM diagrams

Drag and Drop an Image Here

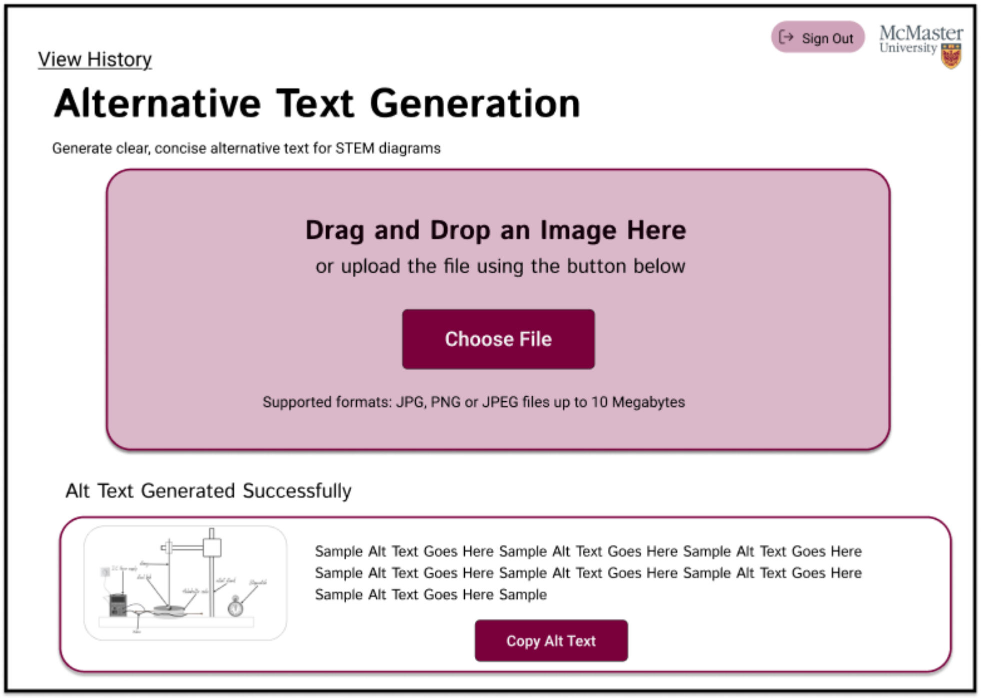
or upload the file using the button below

Supported formats: JPG, PNG or JPEG files up to 10 Megabytes

Upload Failed

File size exceeds 10 Megabytes. Please Try again!

Figure 10: Upload Failure UI



Alternative Text Generation

Generate clear, concise alternative text for STEM diagrams

Drag and Drop an Image Here

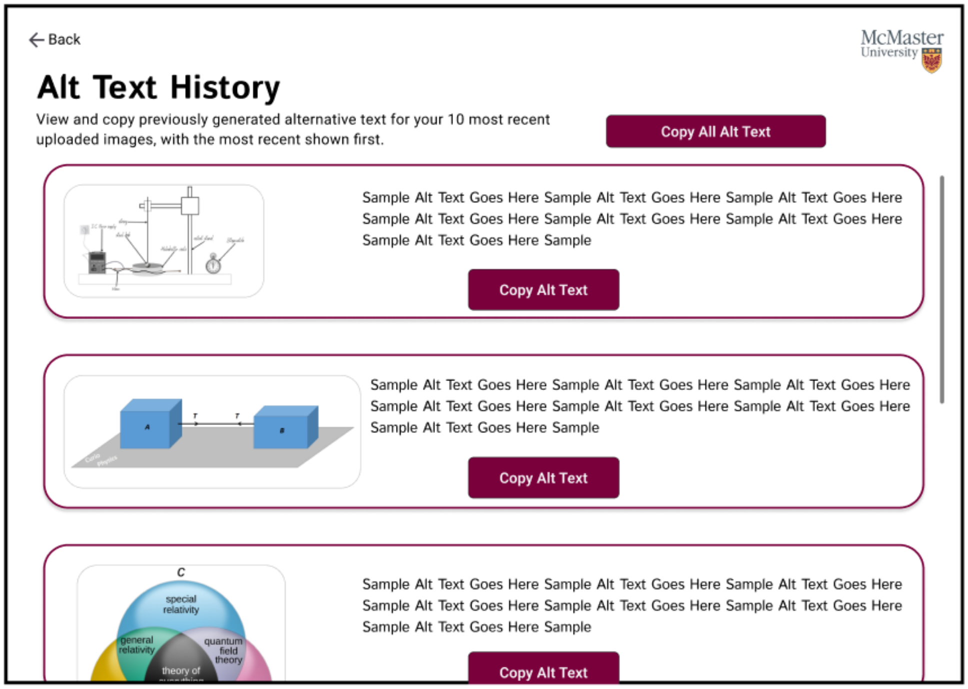
or upload the file using the button below

Supported formats: JPG, PNG or JPEG files up to 10 Megabytes

Alt Text Generated Successfully

Sample Alt Text Goes Here Sample Alt Text Goes Here Sample Alt Text Goes Here Sample Alt Text Goes Here Sample Alt Text Goes Here Sample Alt Text Goes Here Sample Alt Text Goes Here Sample

Figure 11: Alt Text Generated UI



Alt Text History

View and copy previously generated alternative text for your 10 most recent uploaded images, with the most recent shown first.

Sample Alt Text Goes Here Sample Alt Text Goes Here Sample Alt Text Goes Here Sample Alt Text Goes Here Sample Alt Text Goes Here Sample Alt Text Goes Here Sample Alt Text Goes Here Sample

Sample Alt Text Goes Here Sample Alt Text Goes Here Sample Alt Text Goes Here Sample Alt Text Goes Here Sample Alt Text Goes Here Sample Alt Text Goes Here Sample Alt Text Goes Here Sample

Sample Alt Text Goes Here Sample Alt Text Goes Here Sample Alt Text Goes Here Sample Alt Text Goes Here Sample Alt Text Goes Here Sample Alt Text Goes Here Sample Alt Text Goes Here Sample

Figure 12: History Page UI

11 Design of Communication Protocols

Not applicable for this project.

12 Timeline

The team will split the project into three main subgroups. These three subgroups and the current team members within each subgroup for Rev 0 are outlined below. Design decisions across each subgroup will be discussed and made together by the entire team.

1. **AI:** Nawaal, Fiza, Francine
2. **Backend:** Dhruv, Moly, Francine (backup)
3. **Frontend** Dhruv, Moly, Francine (backup)

The development schedules per subgroup for Rev 0 (including tentative dates past Rev 0 and moving towards Rev 1) are outlined below in Tables 18-20. From September 2025 up to the Proof of Concept demontration on November 26th, 2025, planning and elicitation for the Reading4All system was conducted. The official development stages began at the end of December 2025.

AI Subgroup

Table 18: AI Subgroup Development Schedule

Date	**Task**	**Module Associated**	**Team Member(s) Responsible**
12/25/2025 – 01/05/2026	Lock scope of data, set up environments, and acquire datasets	None	All team members
01/06/2026 – 01/11/2026	Data preprocessing, begin training on dataset, metadata labelling	None	Nawaal, Fiza, Francine
01/11/2026 – 01/23/2026	Model fine-tuning and training using Jing's dataset	AIModelTraining, CaptionGeneration	Nawaal, Fiza, Francine
01/23/2026 – 01/30/2026	Implement WCAG compliance checks, and internal metric compliance	InternalMetric-Compliance, WCAGCompliance	Nawaal, Fiza, Francine
02/02/2026 – 02/06/2026	**Rev0**		All team members
02/09/2026 – 02/13/2026	User testing for generated alt text	None	All team members
02/14/2026 – 02/27/2026	Implement feedback from user testing to AI model	FeedbackMetrics, FeedbackLoop, Feedback	Nawaal, Fiza, Francine
02/27/2026 – 03/15/2026	Evaluation of metrics, system integration with backend/frontend	FeedbackMetrics, FeedbackLoop, Feedback	Nawaal, Fiza, Francine

Frontend Subgroup

Table 19: Frontend Subgroup Development Schedule

Date	**Task**	**Module Associated**	**Team Member(s) Responsible**
01/05/2026 – 01/12/2026	Create figma designs for each page	None	Dhruv, Moly, Francine
01/12/2026 – 01/21/2026	Implement UI pages and test screen reader compatibility	LogInScreen, MainScreen, ShowHistoryScreen, UserInterfaceAccessibility, UserInterfaceInteractions	Dhruv and Moly
01/21/2026 – 01/30/2026	Integration with backend system and WCAG testing	None	Dhruv, Moly, Francine
02/02/2026 – 02/06/2026	**Rev0**	None	All team members
02/09/2026 – 02/13/2026	User testing	None	All team members
02/14/2026 – 02/27/2026	Revise UI if needed after testing	None	Dhruv, Moly, Francine

Backend Subgroup

Table 20: Backend Subgroup Development Schedule

Date	**Task**	**Module Associated**	**Team Member(s) Responsible**
01/05/2026 – 01/12/2026	Planning APIs and creating schemas	None	Dhruv, Moly, Francine
01/13/2026 – 01/21/2026	Implement APIs and manual testing	AuthenticationService, BackendController, SessionManagement, ImageValidation	Dhruv, Moly, Francine
01/21/2026 – 01/30/2026	API testing and integration with Frontend and AI systems	Logging	Dhruv, Moly, Francine
02/02/2026 – 02/06/2026	**Rev0**	None	All team members
02/09/2026 – 02/13/2026	User testing	None	All team members
02/14/2026 – 02/27/2026	Revise backend logic if needed after user tesing	None	Dhruv, Moly, Francine

13 Appendix A - Mathematical Representation for *Reading4All - AI Subsystem*

This section provides an overall formal mathematical representation of the *Reading4All* system such that the system can be understood independently of its implementation. Furthermore, specific attempts for the AI trained under the *AI Subgroup* are mathematically denoted with the goal being to explicitly document all attempts made during the training process and how intermediate representations are constructed.

13.1 Reading4All - AI Subsystem Overview

The *Reading4All - AI Subsystem* is a multi-stage vision–language system designed to automatically generate accessible alternative (alt) text for STEM figures. The subsystem operates by progressively transforming a visual input into increasingly abstract representations, culminating in natural-language descriptions suitable for assistive technologies such as screen readers.

Input Space Let,

$$I \in \mathbb{R}^{H \times W \times 3}$$

denote a single RGB input image, where H and W correspond to the height and width of the image in pixels, and the third dimension represents color channels (which are red, green and blue).

Output Space The final output of the AI Subsystem is a sequence of textual tokens:

$$A = (a_1, a_2, \ldots, a_T),$$

where each a_t belongs to a discrete vocabulary $\mathcal{V}$ and T denotes the length of the generated alt text.

System-Level Mapping At a high level, the *Reading4All - AI Subsystem* implements a conditional mapping:

$$\mathcal{F} : \mathbb{R}^{H \times W \times 3} \to \mathcal{V}^T,$$

which is instantiated through multiple training scenarios described in the subsequent sections.

13.2 Mathematical Preliminaries and Shared Notation

The following notation is used consistently throughout this appendix:

- I: input image

- P: number of visual patches extracted from I
- p: patch side length in pixels
- d: hidden embedding dimension of transformer models
- L: number of transformer layers
- θ: set of trainable parameters
- $\mathcal{L}$: loss function

All models used within the *Reading4All - AI Subsystem* are based on transformer architectures and employ attention mechanisms and residual connections.

13.3 Vision Transformer Encoding

All training scenarios begin by converting the input image I into a latent visual representation using a vision transformer encoder.

13.3.1 Patch Extraction

The image I is partitioned into non-overlapping square patches of size $p \times p$. The total number of patches is given by:

$$P = \frac{H \cdot W}{p^2}.$$

Each patch is flattened into a vector:

$$\mathbf{x}_i \in \mathbb{R}^{3p^2}, \quad i = 1, \ldots, P.$$

13.3.2 Patch Embedding

Each flattened patch vector is projected into a d-dimensional embedding space using a learned linear transformation:

$$\mathbf{e}_i = \mathbf{W}_E \mathbf{x}_i + \mathbf{b}_E,$$

where $\mathbf{W}_E \in \mathbb{R}^{d \times 3p^2}$ and $\mathbf{b}_E \in \mathbb{R}^d$ are trainable parameters.

A special learnable classification token $\mathbf{e}_{\text{CLS}} \in \mathbb{R}^d$ is prepended to the patch sequence, yielding:

$$\mathbf{Z}_0 = [\mathbf{e}_{\text{CLS}}, \mathbf{e}_1, \mathbf{e}_2, \ldots, \mathbf{e}_P].$$

13.3.3 Transformer Encoder Layers

The embedded patch sequence is processed by L stacked transformer layers. For layer $\ell \in \{1, \ldots, L\}$, the hidden representation is computed as:

$$\mathbf{Z}_\ell = \text{LayerNorm}\left(\mathbf{Z}_{\ell-1} + \text{FFN}\big(\text{MSA}(\mathbf{Z}_{\ell-1})\big)\right).$$

Multi-head self-attention (MSA) is defined by:

$$\text{MSA}(\mathbf{Q}, \mathbf{K}, \mathbf{V}) = \text{softmax}\left(\frac{\mathbf{Q}\mathbf{K}^\top}{\sqrt{d}}\right)\mathbf{V},$$

where $\mathbf{Q}$, $\mathbf{K}$, and $\mathbf{V}$ are linear projections of $\mathbf{Z}_{\ell-1}$.

The final image representation is taken as the output corresponding to the classification token:

$$\mathbf{h}_{\text{img}} = \mathbf{Z}_L^{(0)}.$$

13.4 Scenario 1: Caption-Centric Vision–Language Learning

Scenario 1 implements a direct vision-to-language pipeline using a small BLIP-based model and scientific caption supervision.

13.4.1 Stage 1: PubLayNet Layout Classification [Zhong et al. (2019)]

Task Definition Given an input image I, the model predicts a dominant layout category

$$y \in \{\text{text}, \text{title}, \text{list}, \text{table}, \text{figure}\}.$$

Classification Head A linear classifier maps the image embedding $\mathbf{h}_{\text{img}}$ to unnormalized logits:

$$\mathbf{o} = \mathbf{W}_C\mathbf{h}_{\text{img}} + \mathbf{b}_C,$$

where $\mathbf{W}_C \in \mathbb{R}^{5\times d}$ and $\mathbf{b}_C \in \mathbb{R}^5$.

Loss Function The layout classification loss is defined as the categorical cross-entropy:

$$\mathcal{L}_{\text{layout}} = -\log \frac{\exp(o_y)}{\sum_{k=1}^{5} \exp(o_k)}.$$

At the time of this document submission, only the vision encoder parameters are updated during this stage, while the language model parameters remain frozen to prevent premature or unstable updates to the uninitialized decoder.

13.4.2 Stage 2: SciCap Caption Generation [Hsu et al. (2021)]

Caption Representation Let a reference scientific caption be represented as a token sequence:

$$C = (c_1, c_2, \ldots, c_T).$$

Autoregressive Decoding The decoder models the conditional probability of each token given previous tokens and the image representation:

$$p(C \mid I) = \prod_{t=1}^{T} p(c_t \mid c_{<t}, \mathbf{h}_{\text{img}}).$$

Cross-Attention Decoder hidden states attend to visual embeddings via cross-attention:

$$\text{Attn}_{\text{cross}} = \text{softmax}\left(\frac{\mathbf{QK}^\top}{\sqrt{d}}\right)\mathbf{V}.$$

Loss Function The captioning objective is the negative log-likelihood:

$$\mathcal{L}_{\text{caption}} = -\sum_{t=1}^{T} \log p(c_t \mid c_{<t}, I).$$

As per our initial attempt the vision encoder is frozen while only the decoder and cross-attention parameters are updated. Freezing the encoder stabilizes training and ensures that the visual features learned in Stage 1 are preserved.

13.5 Scenario 2: Structured Reasoning-Based Alt Text Generation

Scenario 2 introduces an explicit structured intermediate representation between visual understanding and language generation.

13.5.1 Stage 1: PubLayNet Layout Supervision [Zhong et al. (2019)]

This stage mirrors the layout supervision described in Scenario 1 and is used to initialize a layout-aware vision encoder for subsequent stages.

13.5.2 Stage 2: AI2D Structured Representation Learning [Kembhavi et al. (2016)]

Structured Output Space Given an image I, the model generates a structured token sequence:

$$S = (s_1, s_2, \ldots, s_K),$$

where each s_k represents a symbolic component or relationship extracted from the diagram. Example of Structured Components: For instance, each s_k can represent a symbolic component or relationship extracted from a diagram, e.g.,

$$s_k = \text{“arrow: connects A} \rightarrow \text{B”} \quad \text{or} \quad s_k = \text{“circle: highlights key element”}.$$

Conditional Modeling The structured representation is generated autoregressively:

$$p(S \mid I) = \prod_{k=1}^{K} p(s_k \mid s_{<k}, I).$$

Loss Function

$$\mathcal{L}_{\text{struct}} = -\sum_{k=1}^{K} \log p(s_k \mid s_{<k}, I).$$

At the time of the attempt during this stage, the vision encoder is frozen during this stage, and only the decoder cross-attention parameters are updated. This preserves the layout-aware visual features while allowing the model to learn structured symbolic representations from diagrams.

13.5.3 Stage 3: T5-Based Alt Text Generation [Raffel et al. (2020)]

Input Transformation The structured sequence S is serialized into text and provided as input to a T5-based language model.

Alt Text Generation The T5 model produces alt text tokens autoregressively:

$$p(A \mid S) = \prod_{t=1}^{T} p(a_t \mid a_{<t}, S),$$

where $A = (a_1, a_2, \ldots, a_T)$ is the generated alt text token sequence.

Loss Function The alt text generation objective is the negative log-likelihood:

$$\mathcal{L}_{\text{alt}} = -\sum_{t=1}^{T} \log p(a_t \mid a_{<t}, S).$$

At the time of this document's submission and during this stage, the vision encoder remains frozen, the decoder cross-attention parameters from the previous stage are reused, and only the T5 model parameters are updated. Freezing the encoder preserves the learned visual and structured representations, while allowing the language model to specialize in generating descriptive alt text.

13.6 End-to-End System Composition

The final *Reading4All - AI subsystem* is a choice between the two scenarios attempted so far:

$$A = \begin{cases} \text{BLIP}_{\text{SciCap}}(\text{BLIP}_{\text{PubLayNet}}(I)), & \text{Scenario 1} \\ \text{T5}(\text{Pix2Struct}_{\text{AI2D}}(\text{Pix2Struct}_{\text{PubLayNet}}(I))), & \text{Scenario 2} \end{cases}$$

Where,

- Scenario 1: end-to-end captioning;
- Scenario 2: structured reasoning with interpretable intermediate representations.

Design Rationale Each scenario represents a distinct design choice within the *Reading4All - AI subsystem* framework:

- **Scenario 1:** Optimized for end-to-end caption generation using BLIP-based models, with direct supervision from scientific captions.
- **Scenario 2:** Introduces structured intermediate representations (e.g., s_k = "arrow: connects A → B", "circle: highlights key element") to improve interpretability and accessibility while maintaining accurate alt text generation via a T5 language model.

To iterate, freezing certain parameters at each stage ensures stability, preserves previously learned representations, and prevents overfitting when training downstream components on limited data.

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