# ADAM: ADAptive Microlearning using virtual flashcards in blended learning

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## ABSTRACT
University classes require students to learn large amounts of information in order to succeed. Even though most or all of this information is lectured in physical classes, such classes target the body of students as a whole. Therefore, some students may not be able to keep up with them and may miss information due to distractions. Factors like lack of motivation and time constraints may also prevent students from keeping their own regular study schedule. This dissertation describes an adaptive mobile microlearning application based on virtual flashcards and its integration in a university class, as well as the results obtained from the usage data collected and interviews conducted with teachers and students of this class. Both think this approach is very promising and effective, and it seems to benefit both parties. First results suggest that grades increased when ADAM was introduced, even though students only used it near evaluation dates.

### Author Keywords
Adaptive; mobile; microlearning; application; flashcards; blended; learning; university.

### ACM Classification Keywords
H.5.2 Information Interfaces and Presentation: User Interfaces

## INTRODUCTION
We live in an era where information is easily accessible anywhere and at any time. As a consequence, we are also bombarded with information during almost every single minute that we are awake. This results in our brains getting used to look at information and ignore it even if it is potentially helpful [1]. Most of the times this is not a problem since we can access that same information later whenever we need it. However, there are contexts where it is convenient or even crucial to save this information in the long term (e.g. foreign language learning, school classes).

In the context of college education, memorization is an essential requirement for the success of students. Students are evaluated periodically on the materials studied in class and they need to have these materials memorized in order to correctly fulfill the tasks needed to pass those evaluations. Even when these evaluations allow students to access materials, it is still beneficial for the student to know them at least partially as it will avoid wasting evaluation time searching for the answer to every question. University classes are specially demanding when it comes to memorization because usually there are less evaluations per class and each evaluation contains a very large amount of materials that need to be studied. Moreover, the time available to study the materials tends to be somewhat shorter than it should, due to projects, weekly assignments and evaluation date collisions, which suggests that students should take advantage of every fragment of free time they have during the semester to keep class materials up do date in their mind.

Nowadays we can see some attempts to implement a blended learning environment in the context of university classes [2, 3, 4, 5, 6]. The goal is to keep the same physical classroom environment and combine it with a set of virtual tools that each student can use to learn and complete evaluated tasks at their own pace [2, 3, 4, 5, 7]. This approach tries to overcome the issue that arises when there is a number of fixed evaluation dates and students have to study a big chunk of information for each evaluation, which many may not be able to due to time constraints related to other university classes or even personal matters. With blended learning, each student can perform the tasks in the order they choose and when it better fits their schedule. This should result in a more sparse and continued study instead of just the usual bursts resulting from regular classes and evaluation methods, which brings benefits in the long term retention of the class materials [8, 9, 10, 11].

### Problem
The issue with memorization is that it is time consuming and involves repetition, which makes it boring and unappealing [12]. Typically, when trying to memorize something, people tend to dedicate relatively long periods of time where they try to cram as much information as they can, hoping that it will stay there for a while. However, studies have shown that shorter and spaced study sessions are much more effective at storing information in the long term [8, 9, 10, 11]. But due to the repetitive and boring nature of these study sessions and also the lack of time to dedicate to them, it is hard to keep a study schedule that will let us achieve our goals.

In theory, physical classes like the ones we have at a university should proportionate the optimal continued and spaced study sessions that would enable students to learn

effectively. However, because classes are always oriented towards collective learning rather than individual learning, not every student will be able to take full advantage of them. There are many variables at play, like class noise and the teachers' way of expressing themselves, and ultimately everyone has their own personal way of learning things and an optimal pace at which they can learn. Plus, in a physical class, a single distraction can make you miss something of big importance. If, instead, every student had, besides the physical classes, a personalized way to learn where they could study without missing content and they could do this at their own pace whenever they felt comfortable (i.e. motivated, focused and not tired), it should be expected that they would learn more and would overall feel more motivated towards classes as they would always be up to date with the materials. **The current reality is that, even though students should have a continuous learning process and review class materials on their own time after each class to make sure they were always up to date, this just does not happen because of lack of time and motivation.**

### Approach

Microlearning applications have been extensively used to try to overcome memorization issues [8, 13, 14, 15, 16, 17, 18, 19, 12, 20] [21, 22, 23]. The core idea is that study sessions are spread throughout the day and have a short duration. This way people can take advantage of fragments of free time to study instead of having to schedule and dedicate a larger amount of time each day. This brings plenty of advantages, some related to user motivation and time efficiency [15, 19, 12, 18]. Microlearning is also versatile as it can be used with different learning methods like quizzes, flashcards or any sort of minigame.

Flashcards are one of the simplest ways to help people learn facts. They are easy to create and require very little interaction in order to be effective. However, traditional flashcards are hard to use because they require students to physically carry them around whenever they want to study and advanced study strategies are extremely hard to put in practice, especially as the number of flashcards grows. It is also easy to drop a few flashcards and mess the whole structure up. Plus, like every physical object, flashcards can be lost and damaged.

Thankfully, technological advancements have enabled the use of virtual flashcards in any sort of electronic device, overcoming all of these disadvantages [24]. One thing that is important to note is that we can now use software to manage virtual flashcards for us, allowing for advanced and effective study strategies. It is possible to keep track of the ideal time to study each flashcard using spaced repetition algorithms and even to exploit the capabilities of the device we are using to enable context aware learning.

This dissertation presents a microlearning application that uses virtual flashcards to improve students' learning performance in a blended learning environment. We will use an adaptive spaced repetition algorithm that will adjust the inter-study interval of each flashcard based on the overall memorization performance of each user, which is expected to accelerate the learning process by trying to achieve the optimal study interval for each user.

So far there does not seem to have been made a real significant effort to try to introduce a microlearning application into serious learning environments like universities, which motivates this dissertation.

The choice of using virtual flashcards instead of other learning methods was made based on its adequacy to microlearning scenarios and mobile contexts. The most basic version of virtual flashcards requires only a binary input from the user (right or wrong) while still being able to provide a rich variety of media to support learning (e.g. text, audio, images, gifs, videos, usage examples, mnemonics). This makes it a great choice when you take into account that many of the study sessions may take place in crowded and noisy areas. Another relevant factor is that there are already studies that combine virtual flashcards and microlearning and these can therefore be used as a starting point for this dissertation [8, 13, 17].

### Objectives

There are four main objectives in this dissertation.

**Develop an adaptive mobile microlearning application and introduce it in a university class.**

The first main objective is to develop a mobile microlearning application that uses virtual flashcards and an adaptive spaced repetition algorithm that adjusts the inter-study interval of each flashcard based on the overall memorization performance of each user to be introduced in a university class.

**Understand whether there is a positive learning effect in using microlearning in a blended learning environment.**

The second main objective is to determine if the students that frequently used the application consistently had better results in the evaluations than the others who did not use the application or who used it less frequently.

**Determine if students adopted a more continued study strategy.**

The third main objective is to determine if the students felt motivated enough by the application to keep a regular study schedule throughout the semester, instead of quitting after a while or just using it close to the evaluation dates.

**Develop the application in such a way that it can be used in any domain.**

The fourth main objective is to make sure that the developed application can be used to learn materials from any domain, not being limited to learning the materials of a specific university class.

## RELATED WORK

### Learning and cognitive sciences

When using flashcards to study we are actually performing a cued recall. When we combine cued recall with a spaced repetition strategy, we are taking advantage of the testing and spacing effects. These effects have been studied in order to better understand how our memory works and to create a model that explains how memories are forgotten and how the strength of a memory is increased.

#### *Testing effect*

It has been observed in studies that study sessions that involve the subject being tested and then given the correct response increase the memory strength significantly more than study sessions where the information is presented right away and the subject is given some time to look at it. This effect also seems to not be tied to a specific domain, having been observed in a variety of contexts and domains like foreign vocabulary acquisition, word lists memorization, face-name associations and general facts [8, 25, 26, 12].

One important thing to note about the testing effect is that it happens even if there is no outward response given by the test subject. What this means is that the mental retrieval itself is enough for this effect to manifest [26]. This is great because it makes it possible to study in public places, where it is undesirable to produce any sort of vocal response, and it also means that a specific type of entity that the subject needs to communicate with in a specific way is not required, giving us a lot of freedom when implementing a strategy that takes advantage of this effect. The subject can simply look at a cue, try to recall the target mentally, check if the response obtained matches the target and finally provide feedback to any sort of entity in any sort of way that fits the target scenario. This could either be making a gesture to a camera, producing a sound to a microphone, pressing a button on a keyboard or touching a touch screen with the tip of a finger.

It has also been observed that by studying using cued recall tests such as flashcards, where we have tests of the form cue→target, the retention in the opposite direction (target→cue) is also enhanced. This even seems to enhance the free recall of cues and targets. This fact is quite beneficial too for the student because it means that by studying a single flashcard it is possible to get all these additional benefits with no additional effort, making it an efficient study method [25].

#### *Spacing effect*

The spacing effect can be observed when we compare the retention resulting from multiple shorter presentations of a chunk of information and the retention resulting from a single longer presentation of that same chunk of information. The multiple shorter presentations result in a superior retention than the alternative, which means that keeping a regular and non-intensive study schedule results in a more time efficient study than intensive study sessions closer to the evaluation dates [27, 11, 9, 10].

The way our memory works is that when you study a piece of information you will remember that piece of information for a certain time, usually referred to as the retention interval. The retention interval is usually at first quite short and further presentations of that piece of information will increase the retention interval further and further. However, as the retention interval increases, multiple presentations close to one another start to show diminishing returns and the inter-study interval should therefore be increased as well. This means that as the strength of a memory increases, the frequency of study of the pertaining piece of information can be decreased, freeing up time to learn other pieces of information that the student is less familiar with [8, 27].

It has been suggested that this effect could occur because the spacing of the presentations gives our mind some time to forget the weaker parts of a memory, which become more apparent during further presentations and allow us to better correct meanings, clarify ambiguities, correct misconceptions, and identify areas of weakness that need special attention [11, 9].

There is also another theory that says that when we study a piece of information we inherently absorb information from the context where we are studying and that information becomes attached to the information we are trying to memorize. By further spacing the presentations we increase the likelihood of bigger variations in the context we are at and more unique information from that context becomes attached to that memory as well. This attached information can then act like a sort of alternative entry point for that memory, making it easier to access the memory, in the same sort of way that a mnemonic helps us remember things [9].

#### *Forgetting curve*

The way our mind forgets things can be described through a forgetting curve [8, 28]. By looking at forgetting curves it is possible to determine that our minds forget things according to an inverse exponential curve. When there is a spaced presentation of a piece of information the strength of the pertaining memory increases and that memory's forgetting curve becomes less steep, which means that the process of forgetting for that memory becomes more gradual and takes longer, as can be seen in Figure 1.

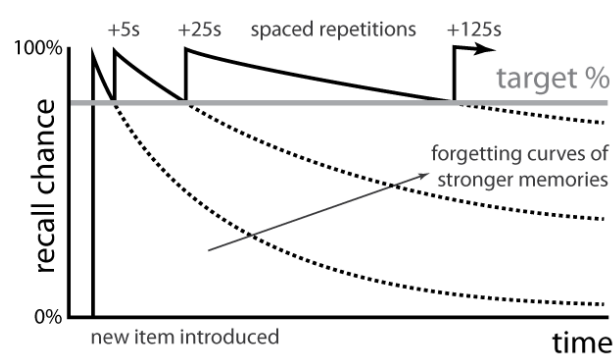


**Figure 1 – Forgetting curve resulting from adaptive spaced repetition learning [8].**

This once again shows us that as the strength of a memory increases the inter-study interval should also be increased in order to compensate for the diminished benefits of further closer presentations. Presentations should only occur when the recall chance of that memory decreases to a certain value in order to obtain the benefits of the spacing effect discussed in the previous section. The recall chance can, thankfully, be predicted using the plotted forgetting curve and it is therefore possible to determine the approximate optimal time to schedule the next presentation.

### Mobile and Microlearning theory

Current widespread learning systems tend to impose time and organizational constraints that do not fit the way people live their lives in modern days [8, 16]. With interactive devices and distractions absolutely everywhere it is hard for people to find time during the day to solely devote to learning. Not only this, but it also requires a big deal of self-motivation to stick to a learning schedule when you know that there is a near infinite amount of more fun activities you could be doing instead. So, researchers are now realizing that instead of focusing on ways to convince people to dedicate a certain amount of time to learning and keeping them motivated, like turning learning activities in game-like activities, a smarter and easier approach might be to try to help people take advantage of the really small time periods where they are not focusing on anything else. Even though it is hard to dedicate a longer period of time to studying, like half an hour or even an hour, there is a huge number of small pauses throughout the day that we could exploit and turn into learning sessions. Actually, these could even be called microlearning sessions since their duration can be measured in merely a few minutes or even seconds. The really short duration, however, does not mean that we will not be able to learn a decent amount because, due to the high frequency of these small pauses, they can quickly add up to a decent chunk of your daily time [29, 12, 30, 31, 20, 23, 15].

Nowadays, people carry mobile smart devices like smartphones, tablets and laptops everywhere they go. It is actually hard to meet someone who does not carry one of these. This means that microlearning activities can be easily introduced into people's daily lives since they will not need to purchase or otherwise acquire any new equipment to get started. Installing an app or accessing a website is all that is needed to instantly start learning on these devices. In every small period of time where people are not focusing on anything, like when waiting for a bus, riding on the metro or even waiting for the food to cook, people can just pull out their smartphones and perform learning activities.

This is basically the foundation of mobile microlearning: taking advantage of every small period of free time throughout the day to learn, no matter where you are [29, 12, 30, 31, 20, 23, 15].

It is possible to tell already that learning apps are moving towards the concept of mobile microlearning but are not quite there yet. Many people are starting to adopt these apps because they realize the benefits they can bring them but quickly stop using them as the initial motivation goes away. The most obvious reason for this to happen is that these apps still focus more on long term retention and not enough on short term retention. This leads to poor initial results and a very slow start. Because of this, people quickly realize that these apps are not giving them the rewards they were expecting and either give up immediately or try something else. Some researchers tried to develop applications that focus more on the short term retention and test subjects gave positive feedback as they felt that, even though they were learning many new contents at a fast pace, if they failed to remember a content, the app would just quickly reinforce the training of that content so they could quickly get it back [8].

An interesting fact about mobile microlearning is that, despite its apparent advantages, apps that try to implement this concept are still just targeting these individual users that try them out for themselves. There has not been a real significant effort to try to put it in practice into serious learning environments like schools. Doing so would allow to improve or even develop new and better algorithms and strategies by testing them on students who could really benefit from using these apps.

### Blended learning

The introduction of a learning app like the one described in this dissertation in a classroom environment like the ones found in a university would constitute a form of what is known as blended learning (or hybrid learning).

Blended learning is the result of mixing a physical learning environment with a set of virtual tools or even a virtual environment meant to assist the learning of the contents covered in the physical environment [2, 3, 4, 5, 7].

The benefits that blended learning brings to the table is that it allows for students to attend the same physical classes they are already used to, where they are thought class contents by the teacher, with whom they can interact at any time to clear up misconceptions, misunderstandings and ambiguities, while also allowing them to progress at their own pace on their free time using the virtual tools provided. These tools can be virtually anything: apps to assist the learning of the contents via games, quizzes or flashcards, a forum where the students can communicate more conveniently both with each other and the teachers at times where they would not be able to, or even a platform where students can submit projects to be evaluated as they complete a set of given tasks in the order and at the pace they desire and better fit their personal skills and schedule. This basically provides a more personalized way for students to learn, study and be evaluated that could not be achieved using just the traditional methods that are used today [2, 3, 4, 5, 7].

Teachers responsible for blended courses reported that the students were able to produce higher quality papers and projects, achieved better results in exams and understood the course materials to the point of being able to have more

meaningful discussions on those materials. It was also reported that both the teachers and the students felt a higher level of satisfaction due to the increased student engagement in learning, which resulted from the enhanced flexibility of teaching and the enhanced interaction with the students [2, 3, 4, 5, 6].

The aim of this dissertation is to create a blended learning environment by introducing a mobile microlearning application that allows the teacher to create flashcard decks that the students can use to study whenever and wherever they want. The application will also adjust the inter-study intervals for each student, providing an extra bit of personalized study. The students in this class will have weekly quizzes that are part of their final grade and it is expected that this application will help them study continuously throughout the semester for these quizzes in order to achieve higher grades.

### ADAM

In this section, we will describe our solution, ADAM, going over our approach, the architecture behind it, the adaptive spaced repetition algorithm used to calculate the inter-study intervals, and the main features of our web application that teachers and students interact with.

### Approach

Our solution was to develop a mobile microlearning application and introduce it in a university class in order to create a blended learning environment, in which students could use the application to learn on their own and at their own pace on their free time outside physical classes.

The materials covered in the class were converted to flashcard decks that were made available to the students, who were then given the option to use the application to study these decks whenever they wanted. However, students could still choose not to use the application and instead study using the lecture slides provided by the teachers or by any other means they saw fit.

The application was developed for the web so that it could be used in any platform, mobile or not. This was to allow any student to access the application in a smartphone, tablet, laptop or desktop computer, widening the range of opportunities to perform learning activities.

The chosen study approach was to use flashcards with binary feedback combined with a time based inter-study interval adjustment strategy based on the Leitner system and the exponential intervals of the Pimsleur algorithm [33, 32]. These flashcards can contain text, images and animated gifs, and more types of content can easily be added in the future in order to enrich the learning experience and give more flexibility in the creation of contents.

The application was developed with the intent of being domain-free, meaning that it can be used to learn contents from any domain. Therefore, it is not limited to the contents of the university class where it was introduced, and can be used in other classes and even to learn numerous other subjects like foreign vocabulary and trivia.

### Architecture

ADAM has a very simple architecture. We have a Node.js instance running in a cloud web server that serves the web application to the users as well as expose a REST API that performs all the back-end operations. This Node.js instance is connected to a MongoDB instance also running in a cloud server, with which it communicates whenever an operation needs to be performed.

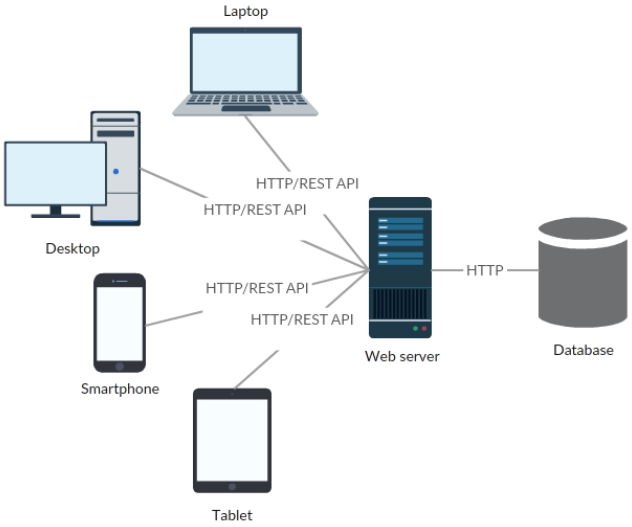


**Figure 2 – The architecture of our solution, ADAM.**

The back-end Node.js code is built on top of the Express framework and uses many open-source and publicly available *npm* libraries to perform all its operations. Most notably, it uses Mongoose to define the database schemas and handle all the database operations (create, find, edit, delete), and Joi to perform the validation of the REST API endpoints' parameters.

The web application served is the same for every connecting device and was developed in such a way that is practical and comfortable to use whether that device is a computer, a tablet or a smartphone. Further details and specifics about this web application will be discussed further in this section.

Besides serving the web application and performing the database operations needed, the web server also includes the adaptive spaced repetition algorithm used to calculate the inter-study intervals, which will also be discussed further in this section.

### Adaptive spaced repetition algorithm

The adaptive spaced repetition algorithm used to calculate the inter-study interval in ADAM is inspired by the algorithm developed for the MemReflex application by Edge et al. [8], and may even be considered a somewhat simplified version of that algorithm, although the equation used is not the same.

Both algorithms are meant to be used with flashcards with binary feedback, where the student is supposed to look at the front of a flashcard and try to remember what is on its back. If the student fails to do so, he sends a negative feedback to the application, and if he succeeds, he sends a positive feedback instead.

The equations of both algorithms output the interval of time in seconds that should pass before the student needs to study that flashcard again. The algorithms are based on the Leitner system (Figure 3), where each flashcard is put into the first box (or bucket) after the first study and moves to the next box on positive feedback or to the first box again on negative feedback [33]. In this system, boxes are numbered and flashcards on boxes with higher number are studied less frequently. The inter-study interval of each flashcard, therefore, depends mainly on the box the flashcard is in.

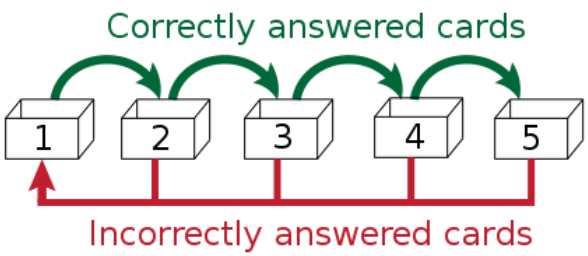


**Figure 3 – In the Leitner system, correctly answered cards are advanced to the next, less frequent box, while incorrectly answered cards return to the first box [33].**

In MemReflex and in ADAM, the base value of each box's inter-study interval is calculated Pimsleur's algorithm [32], using the equation:

$$t = 5^n$$

In this equation, $t$ is the inter-study interval in seconds, and $n$ is the box number which ranges from 1 to infinity.

This equation, however, does not consider the individual performance of the students. Some students memorize things faster and others memorize things slower than the average. Therefore, both MemReflex and ADAM modified this equation in different ways to adapt the inter-study intervals for each individual student. They chose to adjust the exponent in MemReflex and we chose to adjust the base in ADAM.

Another difference from the two algorithms is that MemReflex keeps an interval modifier associated with each box for each student, where ADAM simplifies this and only keeps a single interval modifier for each student, which is shared among all boxes.

The way in which ADAM makes use of this modifier is very simple. Every student starts out with a modifier with a value of zero and the modified equation used to calculate the inter-study interval is the following:

$$t = (5 + \frac{m}{1000})^n$$

In this equation, $t$ is the inter-study interval in seconds, $m$ is the student's individual modifier, and $n$ is the box number which ranges from 1 to infinity.

The modifier is divided by 1000 in the new equation to reduce the impact of changing it to acceptable levels. If it was divided by a smaller number, very tiny changes to the modifier would yield massive time differences, especially in boxes with a high $n$ value, due to the nature of exponentiation.

When developing the algorithm, we established a target recall rate of 90%, the same used in MemReflex. For each student, we keep track of the number of positive feedbacks as well as the total number of feedbacks received. When a student sends feedback after studying a flashcard, we adjust those values accordingly and calculate the proportion between the two. This proportion is that student's recall rate. If the recall rate is equal to or bigger than 90% and the feedback was positive, we increase the modifier by one. If the recall rate is lower than 90% and the feedback was negative, we decrease the modifier by one. In all the other cases, we do not touch the student's modifier at all.

The logic behind these modifier adjustments is that, if a student has a recall rate equal to or higher than 90%, it means that the user is doing better than our target recall rate. Therefore, if he sends a positive feedback we should increase his modifier to space out his inter-study intervals further. This way he can spend more time learning new flashcards and less time reviewing flashcards that he probably recalls very well still. If he sends a negative feedback, he's still over our target recall chance and therefore should not be penalized. If a student has a recall rate lower than 90% and sends a positive feedback it means that the student is moving towards the target recall chance and we should not increase nor decrease his modifier, as it seems to be at a good value for this student. If, however, this same student sends a negative feedback, we should decrease his modifier because the inter-study intervals seem to still be a bit higher than they should and his performance is suffering.

With these adjustments, the student should theoretically come closer to and stabilize near his optimal modifier value over time, which will allow him to recall 90% of the studied flashcards at any given time if he studies whenever the algorithm tells him to. It does not matter if the modifier has a very low value (negative even) or a very high value. The purpose of the modifier is simply to adapt the study frequency for each user and make sure that they are always at or near the target recall chance of 90%.

Edge et al. also rewrote the equation of the human forgetting curve model to represent memory strength as a fixed scaling of the inter-study interval [8, 28]. With this equation, we can calculate a student's estimated recall chance of a card at any moment. The equation is the following:

$$E(recall) = 0.9^{\frac{t_e}{t}}$$

In this equation, $E(recall)$ is the student's estimated recall chance of a card, $t_e$ is the time elapsed since the last review of the card in seconds, and $t$ is the inter-study interval in seconds. The base of the exponentiation is our target recall rate of 90%. Using a different target recall rate would require us to replace that value in this equation.

If the time elapsed is zero seconds, the estimated recall chance is 100%, which makes sense because the student saw the solution zero seconds ago. If the time elapsed is equal to the inter-study interval, the recall chance is exactly 90%, which is our target recall rate goal. If the time elapsed grows higher than the inter-study interval, the recall chance will lower beyond 90% following a reverse exponential curve, which goes according to the forgetting curve (Figure 1).

This estimated recall chance equation is useful because it allows us to show the student his estimated recall chance of a card when he is studying it. However, we chose to only show estimated recall chances equal to or higher than 50%, because we think that while high values motivate the student to try harder to recall the solution, low values might do the opposite and make him quit sooner and not try as hard.

### Application features

ADAM uses the Fénix platform used in Instituto Superior Técnico as a third-party authenticator. Users login via Fénix using their university credentials without having to create an account within ADAM.

The application allows the creation of courses, semesters, decks and flashcards in a structured hierarchy: courses are the root, semesters are created inside courses, decks are created inside semesters and flashcards are created inside decks. All of these can be edited after creation, and decks and flashcards can be deleted as well. Additionally, semesters can be cloned even from one course to the other, retaining their decks and their respective flashcards, saving the effort of recreating them from scratch. Individual decks can also be cloned between different semesters, which can also be from different courses. Decks can also be imported and exported in a JSON format.

Each deck has a leaderboard where users can see how they are progressing compared with their peers. Each semester has a similar leaderboard as well, which shows the progress made on all the decks in that semester.

ADAM contains two independent role systems. One global to the application and one self-contained in each course. The global roles are used to distinguish between admins, who can manage other users' roles and perform every task in the application without limitations, superadmins, which are the same as admins but cannot be demoted, teachers, who are allowed to create courses, and students, who cannot create courses. The role system self-contained in each course allows assigning the role of course teacher or course admin to any user in the application, no matter what their global role is. When a teacher creates a course, he is automatically assigned as the only course admin of that course. Course admins can manage the roles and perform every task inside that course. Course teachers cannot manage the roles, nor create or edit semesters in that course, but can perform any task inside any of the existing semesters without limitations (like creating, editing and deleting decks and flashcards).

Course teachers and admins can view the stats of a deck, which shows, for each card in that deck, the number of correct answers, the total number of answers, and the corresponding percentage.

Students can enroll in semesters that were not flagged as closed by a course admin. However, semesters can be protected with a password to control who can enroll. After enrolling in a semester, students can study any of the decks in that semester, visualize the cards in those decks (either one at a time or all at once) and consult the semester leaderboard as well as the decks' leaderboards. In the page of each deck, students can see some stats about their progress in that deck, like the study history for the last 7 days, the number of cards they have learned out of the total number of cards in that deck, and the estimated recall chance associated with the entire deck.

When studying a deck, students take advantage of the adaptive spaced repetition algorithm, which makes them review cards when they are due for review and lets them learn new cards when none are due for review. If they already learned all the cards and none are due for review, they can still study. The application will show them random cards for them to practice until another card becomes due for review.

When reviewing a card, if the estimated recall chance associated with that card is equal to or higher than 50%, that estimated recall chance becomes visible to the student to try to make him try harder to recall the back of the card.

## EVALUATION

ADAM was introduced in the class of *Multimedia Content Production* of the Master's degree in Engineering Systems and Computer Engineering at Instituto Superior Técnico. During this time, we collected usage data from the students who used it. At the end of the semester the teachers of this class provided us the grades of each student so that we could analyze them along with the data collected. We also conducted interviews with some of the teachers and students of this class, as well as usability tests with 5$^{th}$ year Master's students from a few different areas of study, in which they performed tasks that a university teacher would perform when using the application in his classes.

### Practical application in a university class

ADAM was introduced in the *Multimedia Content Production* class after 3 of the 9 mini-tests of the class had been done already. Only the best 8 grades out of the 9 count for the final grade of the students. Because of this, the 9$^{th}$ mini-test had a lot of zeroes and other extremely low scores, and we decided to exclude it from our analysis. We also excluded all students that had any zeroes in the remaining mini-tests, since we did not want to taint our results with

students that were not taking the class seriously. This left us with 73 students remaining out of the 97 enrolled in the class.

The grades of each mini-test vary from 0 to 750. In Table 1, we can see that the grades were higher during the period in which ADAM was available. For mini-test 8, we failed to create the deck of one of the lectures being evaluated, and the grades of this mini-test fell back down to the range they were in before ADAM was introduced, which suggests there was some correlation.

**Table 1 – Multimedia Content Production mini-test grades. Green cells represent mini-tests where ADAM was available for the students of this class.**

| Mini-test | Average grade | Median grade | IQR of the grades |
|---|---|---|---|
| 1 | 371,5 | 375 | 150 |
| 2 | 415,1 | 450 | 150 |
| 3 | 475,3 | 475 | 250 |
| 4 | 502,4 | 450 | 150 |
| 5 | 503,4 | 450 | 450 |
| 6 | 603,4 | 600 | 200 |
| 7 | 580 | 600 | 300 |
| 8 | 473,6 | 450 | 225 |

We then compared the grades of the 36 most active ADAM students with the 37 least active students to see if the most active students had gotten better grades. This was not the case, which went against our expectations. However, this does not mean that ADAM did not help at least some of the students of the class. Maybe, without ADAM, the most active students would have gotten even worse grades, and the reason they were so active in ADAM might have been that they needed all the help they could get.

The data collected further revealed that students studied mostly on the day of the evaluations and about half as much on the day before, which proves that they did not follow a continued study schedule as would be optimal. An interesting observation is that students were much keener in studying using the adaptive spaced repetition algorithm than by manually viewing the flashcards of a deck, which suggests that they find the study mode a better way of studying.

### Interviews

#### *Student interviews*

We interviewed around 30 of the students of this class, which were all from the Taguspark Campus.

These student interviews revealed that some students were afraid of using ADAM because they thought it was possible that it did not have everything that the class slides had, and that they might miss information by studying with it. Other students said they gave up from ADAM because the flashcards were not similar enough to the questions on the mini-tests and were afraid of wasting time using it. The rest of the students said they used ADAM to study and believed that the adaptive spaced repetition algorithm was very effective, but thought that it could be toned down to be less pushy in the early stages of study of a flashcard, allowing for more learning and less reviewing per study session.

The students interviewed gave good feedback about how simple, fast and good looking the application was, and made good feature suggestions, some of which we implemented after the interviews.

#### *Teacher interviews*

We interviewed two of the teachers of this class, which seemed very excited with ADAM and its concept. They thought there was a real need for such a tool and said that they already had implemented other kinds of measures to improve this class, which cost them a lot of time and effort. However, the measures they implemented only affected the practical aspects of the class and they believe ADAM could be a great addition to help improve the theoretical aspects. Like the students, they made some good suggestions, some of which we also implemented after the interviews. One important point to raise from these interviews is that the teachers thought the application could help not only the students but the teachers as well, by giving them more feedback on the students' progress than they had access to currently.

### Usability tests

The usability tests were performed with ten 5$^{th}$ year Master's students, who performed tasks that a university teacher would perform when using the application in his classes. These tests showed that ADAM is believed to be very simple, complete, customizable, practical, fast and easy to use even for complete beginners. Very few mistakes were made and the problems pointed out were the need of more navigation elements and the apparently disorganized placement of some of the buttons in the application. Since these students were from a few different areas of study, we asked them if they thought ADAM could be used in some of their classes and every single one of them said that it could definitely be used in the vast majority of their classes, since most, if not all, required vast amounts of memorization of concepts and definitions.

## CONCLUSION

The teachers of the class of *Multimedia Content Production* of the Master's degree in Engineering Systems and Computer Engineering at Instituto Superior Técnico interviewed think there is a real need for a tool to help students study the theoretical concepts of their class. They have already spent many resources setting up a blended learning environment with gamification aspects so that students can have an iterative evaluation process, where they submit a project, receive a grade and feedback, and can then resubmit it after improving it based on the feedback in hopes of improving their grade. However, they were only able to

apply this to the practical evaluations of this class. The theoretical evaluations of the class still follow the traditional pattern where students do the test and get a grade, but don't get a chance to improve that grade. Therefore, they think ADAM would be a great addition to their blended learning environment, allowing students to have an iterative, interactive and personalized way of studying while getting feedback on what they need to improve and how good they are doing, and to compare their progress with their peers to see if they are ahead or falling behind. One of the teachers said he even believed ADAM would be a great addition to many other classes as well, and not just this one. Besides helping students, ADAM could also be used for teachers to follow the progress of their students and identify problems with their materials in order to improve them or explain and explore them further in the theoretical and practical classes, benefiting both sides.

Interviews of students of this class also revealed that students think ADAM helps them learn with less effort, because all they need to know is already ready for them to learn within the application, and that the concepts they learn with it really stick in their memory effectively. However, they revealed that they only studied on the day of the evaluations and one or two days before, not really following a continuous study schedule. Many also revealed that they did not trust the application enough because they were afraid there was not as much information there as was in the class slides, or that they gave up because the flashcards were not sufficiently related with the evaluation questions and that they were wasting their time studying them. Most also thought that the adaptive spaced repetition algorithm was very effective but could be toned down to be less pushy in the early stages of study of a flashcard, allowing for more learning and less reviewing per study session.

Usability tests performed with ten 5$^{th}$ year Master's students, who performed tasks that a university teacher would perform when using the application in his classes, showed that ADAM is believed to be very simple, complete, customizable, practical, fast and easy to use even for complete beginners. Very few and innocuous mistakes were made during the usability tests, having been immediately corrected by the subjects themselves and not happening again for the rest of the test. They also pointed out a few things that could be improved, like more navigation elements and the better placement of some elements like buttons. The subjects were from a few different courses and all thought that ADAM could definitively be used in plenty of classes of their areas of study, since most, if not all, required memorization of concepts and definitions, as well as being able to identify and categorize different things. One of the subjects even said that he believed the application could be used to study every kind of theoretical concept.

Looking at the grades of the students of the *Multimedia Content Production* class and the data collected in ADAM, during the time in which they used it to study for the theoretical evaluations of this class, allowed us to observe that grades were consistently higher after ADAM was introduced in the class, having fallen down again to the previous range when we failed to create the deck of flashcards of one of the lectures that was tested. However, further analysis showed that the half of the students that were least active in the application managed to get consistently higher grades than the most active half, which went against our expectations. However, this does not necessarily mean that ADAM did not help at least some students achieve better grades than they would if it was not available. Maybe, without ADAM, the most active students would have gotten even worse grades, and the reason they were so active in ADAM might have been that they needed all the help they could get. The data collected further revealed that students studied mostly on the day of the evaluations and about half as much on the day before, which proves that they did not follow a continued study schedule as would be optimal. An interesting observation is that students were much keener in studying using the adaptive spaced repetition algorithm than by manually viewing the flashcards of a deck, which suggests that they find the study mode a better way of studying.


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