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Tiago Salgado de Magalhães Taveira Gomes

ALERT® STUDENT. A Platform for Medical Education

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Mestrado Integrado em Medicina

Área: Educação Médica

Trabalho efetuado sob a Orientação de:
Doutor Jorge Guimarães
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Profª Doutora Maria Amélia Ferreira

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Projeto de Opção do 6º ano - DECLARAÇÃO DE INTEGRIDADE

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Dedicatória

Ao Doutor Jorge Guimarães, por acreditar na minha vontade e me ter desafiado a encetar a maior aventura da minha vida,

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Ao meu irmão, por constantemente me fazer repensar as prioridades... a primeira, as Pessoas,

Aos meus Pais, pelo seu apoio incondicional e pelo seu exemplo,

... a eles os meu Amor.

MESTRADO INTEGRADO EM MEDICINA

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Título do Projeto: ALERT® STUDENT. Uma plataforma para a educação médica.

Resumo:

A educação médica constitui uma área de crescente complexidade não apenas em virtude do constante desenvolvimento das ciências da saúde mas, também, devido à evolução da tecnologia associada a programas de ensino e aprendizagem orientados para estudantes e profissionais da saúde. Assim, a aprendizagem médica eficaz, necessitando de um considerável investimento de tempo, configura atualmente uma questão de grande relevância entre docentes e discentes.

Neste contexto, e tendo em consideração as diretivas no âmbito da educação de profissionais de saúde, nomeadamente no ciclo pré-graduado de educação médica, o presente estudo tem como objetivo o desenvolvimento de ferramentas para gestão do estudo, as quais permitam aos estudantes atingir os objetivos de aprendizagem otimizando o seu tempo da melhor forma.

Nesse sentido, foi desenhado um sistema que alavanca tecnologias *web* e *mobile*. Foram criadas entidades de *Instituição* e de *Grupo* para representar disciplinas e turmas. A entidade *Sebenta* foi criada para representar composições customizadas de materiais de estudo, construídas com base em blocos denominados *Flashcards,* os quais podem ser agrupados por *Tópicos*. Os *Flashcards* são divididos em *Componentes de Flashcard* que codificam *Conhecimento* e *Questões.*

O sistema permite o estudo e a avaliação do conhecimento, utilizando um ambiente orientado para a aprendizagem, o qual disponibiliza ferramentas que facilitam a navegação do conteúdo, permitindo sublinhar texto, tomar notas, gerir tempos de estudo e filtrar conteúdo de acordo com o conhecimento prévio do utilizador. Os dados adquiridos são disponibilizados utilizando diferentes visualizações info-gráficas.

Este sistema constitui um passo importante para permitir a futuros médicos ultrapassar os desafios da gestão de informação e da aprendizagem contínua, competências centrais do médico do século XXI. As ferramentas disponibilizadas podem ser usadas para gerir, planear e definir objetivos de estudo baseado na evidência do desempenho pessoal e coletivo. Estas ferramentas podem ser úteis para melhorar o desempenho científico e prático dos profissionais no futuro.

Palavras-chave: Educação médica; Gestão da informação; Retenção de memória; E-learning; Aprendizagem baseada na evidência; Aprendizagem customizada; Aprendizagem centrada no estudante;

ALERT® STUDENT. A Platform for Medical Education

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Keywords

Medical education; Information management; Memory retention; E-learning; Evidence-based learning; Tailored learning; Student-centered learning

Abstract

Medical education is an area of increasing complexity due both to the increasing data achievement in Health Sciences and also to the technology associated with programs of teaching/learning towards the education of medical students and professionals. Successful medical learning requires a considerable time investment and is now a matter of profound concern among educators and professionals.

In this context and taking into account the education directives of health professionals, namely in undergraduate medical education, this study is aimed to develop study management tools that are able to provide students with ways to achieve learning goals with optimized time investment.

A system that leverages web and mobile technologies has been devised - ALERT® STUDENT. We used *Institution* and *Group* entities to represent courses and classes. A *Notebook* entity was created to represent custom compositions of learning material, built using blocks named *Flashcards* that are grouped by *Topic* entities. *Flashcards* are split into *Flashcard components* that encode *Knowledge* and *Question*s.

The platform allows study and assessment of knowledge using a learning-oriented environment providing tools to easily navigate content, highlight text, take notes, track study time and filter content based on user previous knowledge and defined objectives of the course. Collected data is displayed using different info-graphic views.

This application is an important step to help future physicians meet the challenges of information management and continuous learning, core competences for the physician of the XXI century. The tools provided can be used to manage, plan and set study goals based on personal and peer performance evidence. Additionally, they may be beneficial to help students become better scientifically prepared and skilled clinicians in the future.

Introduction

Medical education is an area of increasing complexity, considering the view of education of health professionals for the XXI century [1] [2]. Successful medical learning requires a considerable time investment to be achieved, not only in the development of core and specific competencies, but also in the ability to transfer basic competencies namely at the cognitive level to the clinical setting by integration of multiple information sources [2] [3]. The *Institute for International Medical Education Core Committee* (IIME) has defined a set minimum essential core competences and grouped them under seven broad educational domains: professional values, attitudes, behavior and ethics, scientific foundation of medicine, clinical skills, communication skills, population health and health systems, management of information, and critical thinking and research [4]. A culture of long-life learning, that demands a regular commitment, is now identified as a role towards the achievement of clinical competence and a requisite for professionalism [5]. The present work focus on how information management can be optimized to improve student knowledge outcomes through the development of a online application that aims to answer those requests and improve learning in the field of undergraduate medical education.

Information management

Considering the incremental pace of knowledge achievement, it is important to note that for future clinicians, meaningful clinical performance may require preparation in addition to the one delivered in medical school. Without disregarding experience, skill and general knowledge acquired, students are investing a part of their time into learning materials that may be partially outdated by the time they start clinical practice. Thus, medical education need not only to focus on the development of theoretical, technical and human competences, but also in instilling a culture of continuous self-improvement that considers effective management of information [6]. This is an important point, since over commitment to meet learning demands may decrease ability to cope with other life activities and negatively affect professional performance [7] [8].

This is why it is important to develop tools that are able to provide undergraduate students with ways to achieve the defined learning goals at smaller time expense. From our perspective, this can be achieved through personal study management tools that guide the learning process, pinpoint difficulties, optimize study time and comprehensively encompass the medical curriculum, in such a way that the student may attain a beneficial effort-reward balance [8]. To our knowledge, tools used nowadays to aid in learning still do not fully encompass these goals [9].

Content delivery and variation

There are tools that address specific learning needs through the leverage of technology, as it is the case of systems built for the study of anatomy using 3D visualizations [10] [11], or for the study of cardiac sounds through audio recordings with visual feedback [12]. Moreover, some applications deliver content through the use of web and mobile technologies, making it easily accessible in a variety of settings [13] [11]. Despite the great value of presenting of information in meaningful and convenient ways, it is usually difficult to adapt pre-existing solutions to more specific learning requirements, leading to the development of custom solutions in some environments [14].

Variations in medical curricula

Even though scientific knowledge is of universal application, the relative importance of knowledge may vary depending on epidemiological, cultural or local context [15]. Additionally, medical schools and teachers may emphasize knowledge differently, depending on school tradition, clinical experience, school research lines, areas of interest or resource constraints [15]. These factors may influence medical teaching and the selection of learning resources [14].

Memory retention

Medical knowledge is vast and requires a significant amount of effort to learn and retain. The hardships required for such feat often drives students to learn and retain knowledge enough time to meet course goals, that is afterwards partly forgotten [16]. Therefore, students need tools that may help them retain knowledge for longer periods and easily identify harder to learn materials [17].

A few tools are concerned with the problem of memory retention. Available general memory retention tools, used for memory intensive tasks such as learning a new language can also be used by medical students [18]. These tools are based in flashcard systems that associate questions with specific answers [19]. Study sessions are oriented by the questions that the student is required to mentally answer and then grade according to his/her perception of knowledge. These systems use this input to schedule content-specific review sessions, thereby allowing knowledge to be retained at a decreased expense. [19].

There are also tools that encompass memory retention software and pre-made content, together with tools to manage study and track progress [20]. However, these are proprietary tools built to meet specific goals, such as the *United States Medical Licensing Examination*, and therefore may be used only to small extents to meet the specificities of the different medical curricula [21] [22].

Additionally, increasing the number of learning resources shifts learning to an exploratory approach, which leads to a decrease in performance by virtue of increased content variance. In contrast, limited-learning approaches bring focus upon a smaller amount of resources that reduces material variance and stimulates insight deepening. [23]. Thus, students would benefit from a centralized learning environment that can become a main stay for their studies.

E-learning environments and evidence based learning

The application of new learning technologies has emerged as a main stream in medical education [24]. Many schools today adopt e-learning solutions, that are known to simplify document management and sharing, communication, as well as student evaluation and grading [25]. However, these tools focus mainly on maximizing efficiency of management tasks related to the process of teaching. In this context, there are solutions that allow free access to online learning environments composed by lecture videos, notes and exams [26]. Even though these systems may act as a central content reference, they still do not provide students with useful analytical data that can be used to take decisions regarding study sessions and personal learning progress. Successful study management will be possible through the creation of tools that are able to analyze and track student progress in detail [27].

Providing students with such tools would be an important step towards the implementation of the IIME guidelines regarding information management [6]. Tutor participation in blended-learning environments, beyond the limits of traditional classes and learning sources would also be beneficial. Teachers could track student progress and difficulties, meaningfully steering learning sessions and student assessment through gathered performance evidence, as recent tools are starting to allow. [28] This would represent a move towards blended-learning environments that are known to positively affect student and teacher engagement [29].

Understanding this situation a novel system was devised aiming to address these issues, so that students may be able to better manage time needed for successful learning and personal achievement. This system was developed by *ALERT Life Sciences Computing*, a Portuguese medical information technology company. It was released as a new version of a previously existing application named ALERT® STUDENT. All the functionalities presented are new and were not part of the previous application.

Methods

Technologies

The present application was built in accordance to current web standards. The user interface was built over *HyperText Markup Language* (HTML) [30], *Standard Vector Graphics* (SVG) [31], *JavaScript* (JS) [32] and *Asynchronous JavaScript and XML* (AJAX) [33] technologies providing rich online user experience oriented towards the upcoming HTML5 standard. The application layer of the system was built using *JAVA* technology [34] over the *Play!Framework* [35]. The database layer was built using *ORACLE* database systems [36]. A representational state transfer (REST) interface for mobile clients was created, and a simplified client application for apple iOS5 over the iPhone was developed.

The *Medical Subject Headings* (MeSH) [36] standard from the *United States National Library of Medicine* [37] was used for content coding.

Content catalog mechanism

Content was organized by theme. To achieve this the entity *Topic* was created, representing medical concepts and themes related to a medical area. Each *Topic* can have a single type, multiple terms and multiple relationships of various types with other topics. This way, each *Topic* is intended to represent a theme in which content is created.

Content internal structure

Content was divided into small blocks that can be studied and understood independently, by using the concept of flashcards. Each *Flashcard* entity has a front with learning content and a back with questions regarding that content. The *Flashcard* entity can be composed using four different *Flashcard components*: (a) *Fact* - a short and meaningful declaration or assertion; (b) *Detail* - an explanation, description or example that illustrates in detail the content of a *Fact*; (c) *Image* - an image that holds relevant learning material; and (d) *Question* - an open-ended question that can be linked to another *Flashcard component* containing content to answer the *Question*. A *Flashcard component* may have multiple *Questions*. Each *Flashcard* has a category, such as *treatment* and *diagnosis*, among others.

Notebooks · Adaptation to learning requirements

In order to adapt to specific learning goals, an entity called *Notebook* was created, which is an ordered collection of *Topics* and *Flashcards*. *Topics* can be added to *Notebooks* and can be positioned in any order. *Topics* can be linked recursively to represent sub-*Topics*. *Flashcards* from *Topics* can also be added in a custom order to compose a *Notebook*.

Groups • Localization of content

The entities *Institution* and *Group* were created to aggregate knowledge within the context of a medical school and allow sharing of content within institutions. An *Institution* represents a medical school. *Groups* aggregate users, *Notebooks*, *Topics* and *Flashcards*. Multiple *Groups* can belong to an *Institution* or they may exist independently. For example, a *Group* may represent a class, a course or a study group. *Groups* have roles and access rules. The member role allows communicating within the *Group* and grants access to *Notebooks*. The administrator role allows member and *Notebook* management.

Topics and *Flashcards* created within *Institution Groups* are made available to all other *Groups* within the same *Institution* and can be included in other *Notebooks*. Editing *Flashcards* from other *Groups* is not possible unless a user is an administrator of both *Groups*. *Groups* can also be created independently of an *Institution*. Materials created in such a *Group* will not be shared by other *Groups*. A default un-editable set of *Topics* and *Flashcards* was provided to be used by all *Groups*.

Study Mode & Quiz Mode • User performance data

A *Study*-oriented environment was devised where a *Notebook* is visualized in an ordered *Flashcard* column segmented by *Topics*. For each *Flashcard* and for each user, time taken to study, number of study times, user notes and user text highlights are recorded. Additionally, a *Quiz*-oriented environment was created to assess student perception of retained knowledge. Through this environment time taken to answer and *Question* percept-knowledge (*QPK)* were recorded for each user and *Question*. *QPK* is classified on a Likert scale from 1 (full knowledge) to 4 (no knowledge). *Computed Flashcard knowledge* (*CFK*) can then be given by considering recorded QPK for *Flashcard components*.

Entities and relationships described are shown in the UML diagram on Figure 1.

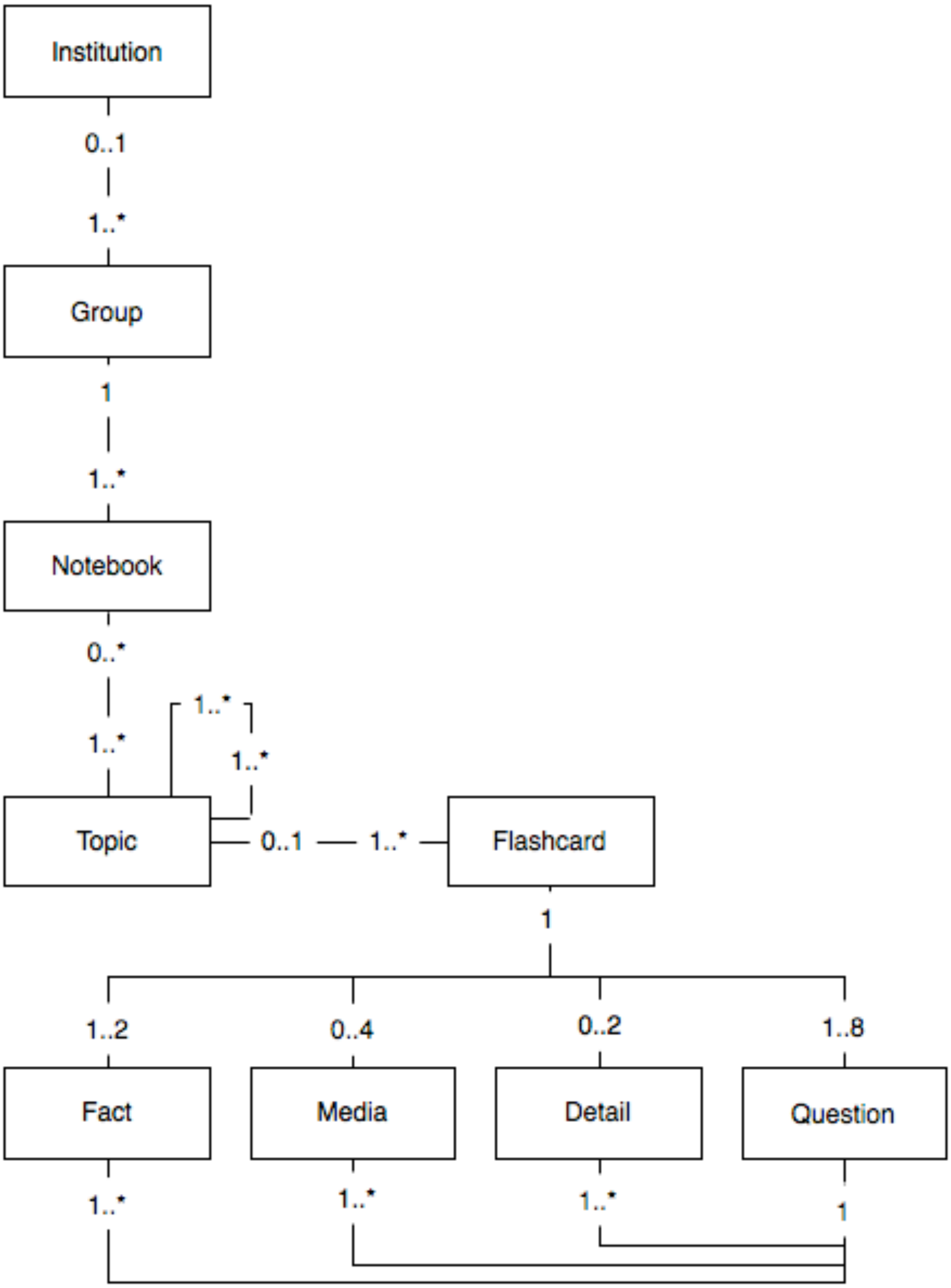

Figure 1 - Simplified Entity relationship UML diagram.

System usability and adoption surveys

System usability and feature usefulness were assessed. 48 students used the *Study Mode*, the *Quiz Mode* and notebook info-graphic views during two sessions of one hour to study a *Notebook* on molecular biology. In the end of each session students filled two online surveys. A survey on system usability and tool usefulness was applied in both sessions. Another survey regarding willingness to adopt the system as a reference tool was used in the last session. Student agreement to each item was assessed using a 4 grade likert scale: 1 - complete disagreement; 2 – partial disagreement; 3 – partial agreement; 4 - full agreement. Paired sample t-test was used to compare differences in the system usability and tool usefulness survey answers between the two sessions. Significance level was fixed at 0.05.

Results

A final solution was implemented as web application (Figure 2) with a mobile client extension for iPhone. The website structure (Figure 3) was divided into core areas that match identified needs.

Figure 2 - ALERT® STUDENT Homepage

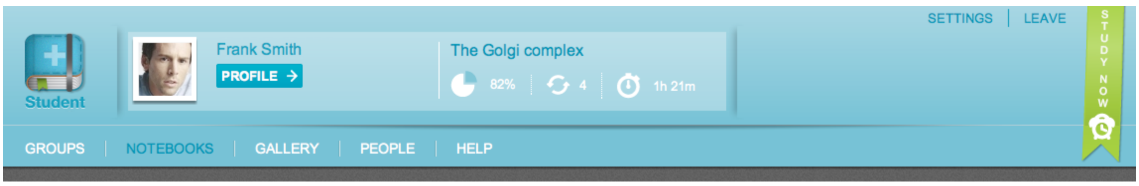

Figure 3 - Application main menu with links to the main application areas. The header also lists the last studied *Notebook* as well as study status. The 'Study now' strap allows to return the place the last *Notebook* was previously left.

Groups

An area for *Groups* (Figure 4) where users can search, subscribe and request invitation for *Groups* was created. *Groups* were split into 3 categories: (a) *Groups* to which the user belongs; (b) *Groups* from the user *Institution*; (c) *Groups* from outside the *Institution*. The scope for searching *Groups* from outside the *Institution* was limited to the user language.

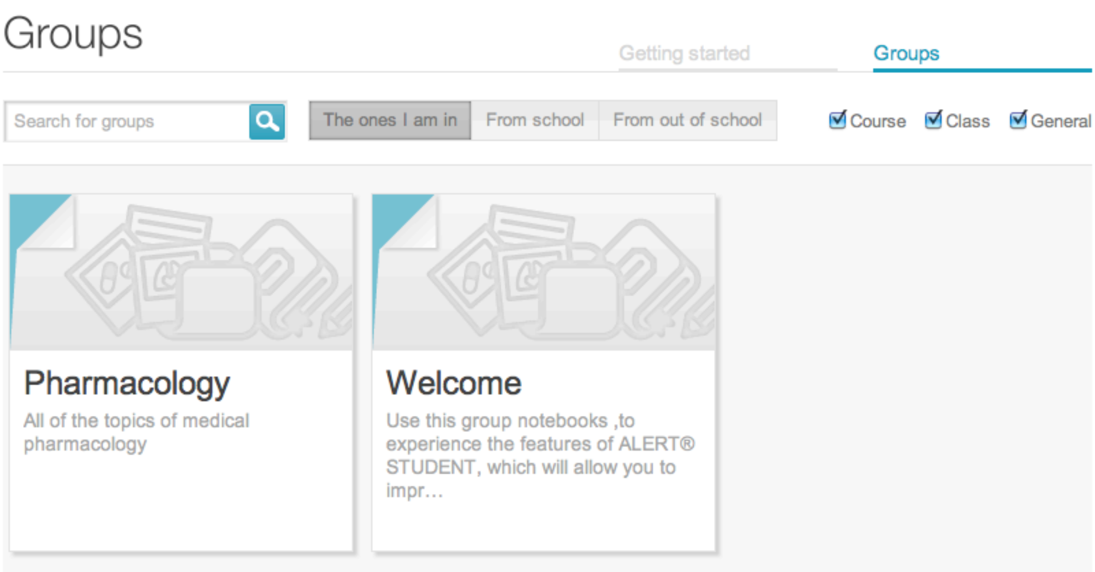

Figure 4 - *Group* list page where the user can search for existing *Groups*. A search bar and filters are provided to narrow search results

Groups were divided into 4 sections: (a) a wall for posting and commenting where users can communicate (Figure 5); (b) a searchable member list, where administrators can additionally invite, approve invitations, block and promote members (Figure 6); (c) a *Notebook* area where members can access and subscribe *Notebooks* and administrators can create or edit them (Figure 7); (d) a *Group* profile section where users can see a summary of *Group* contents (Figure 8).

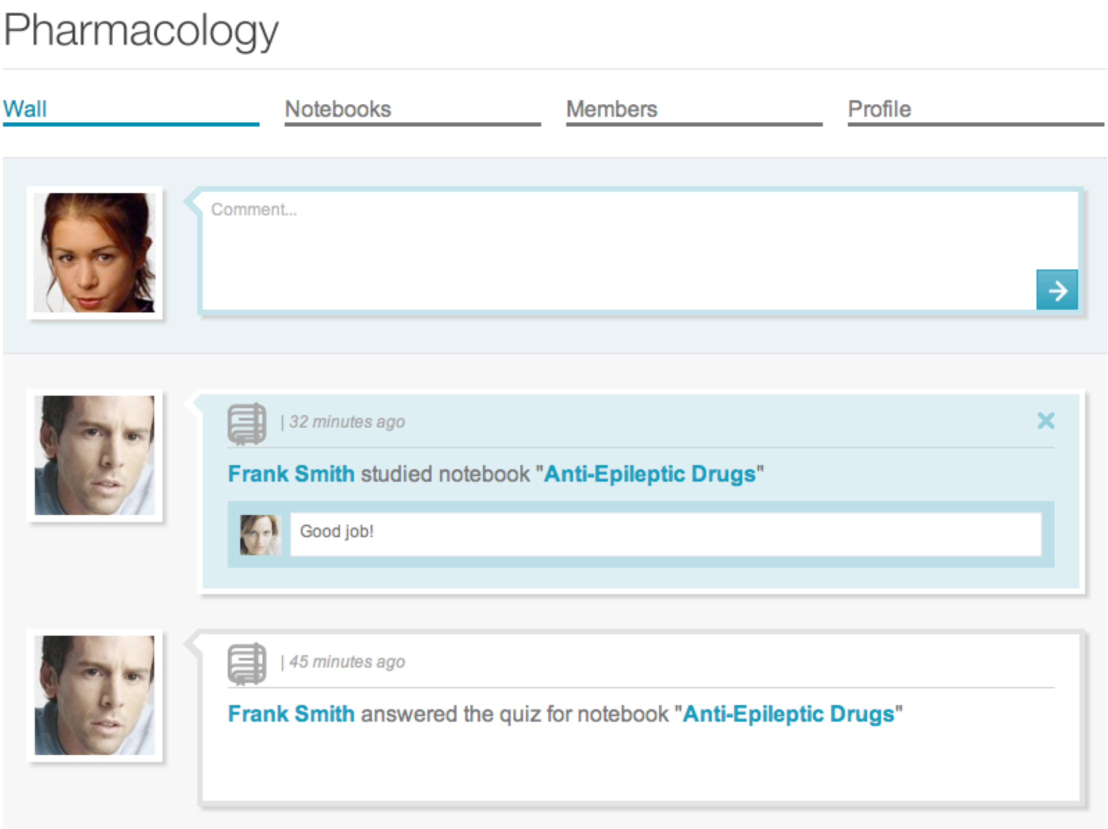

Figure 5 – A *Group* wall. The title indicates the *Group* name and the menu bar indicates the *Group* pages sections. A list of user posts is presented.

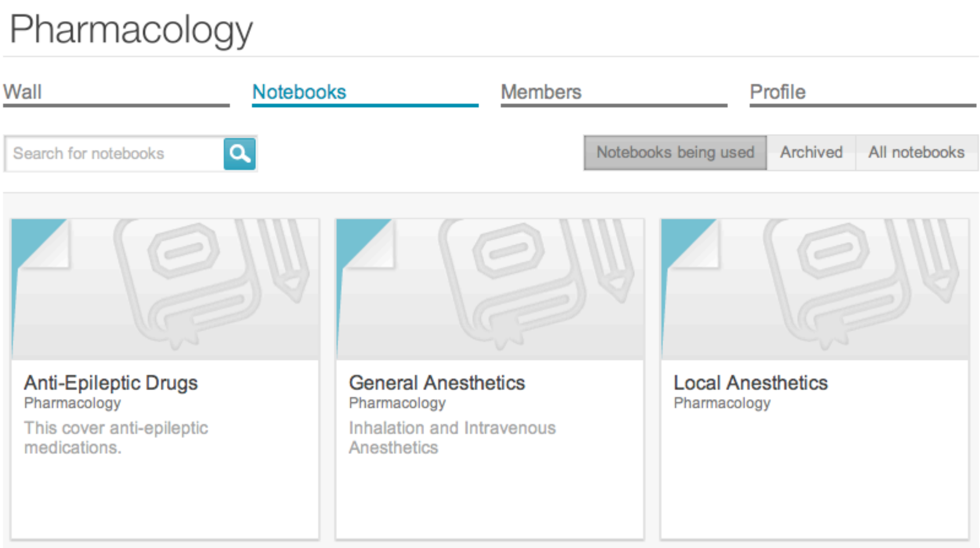

Figure 6 – A *Group Notebook* list. *Notebooks* can be searched using the search bar and the *Notebook* status filters.

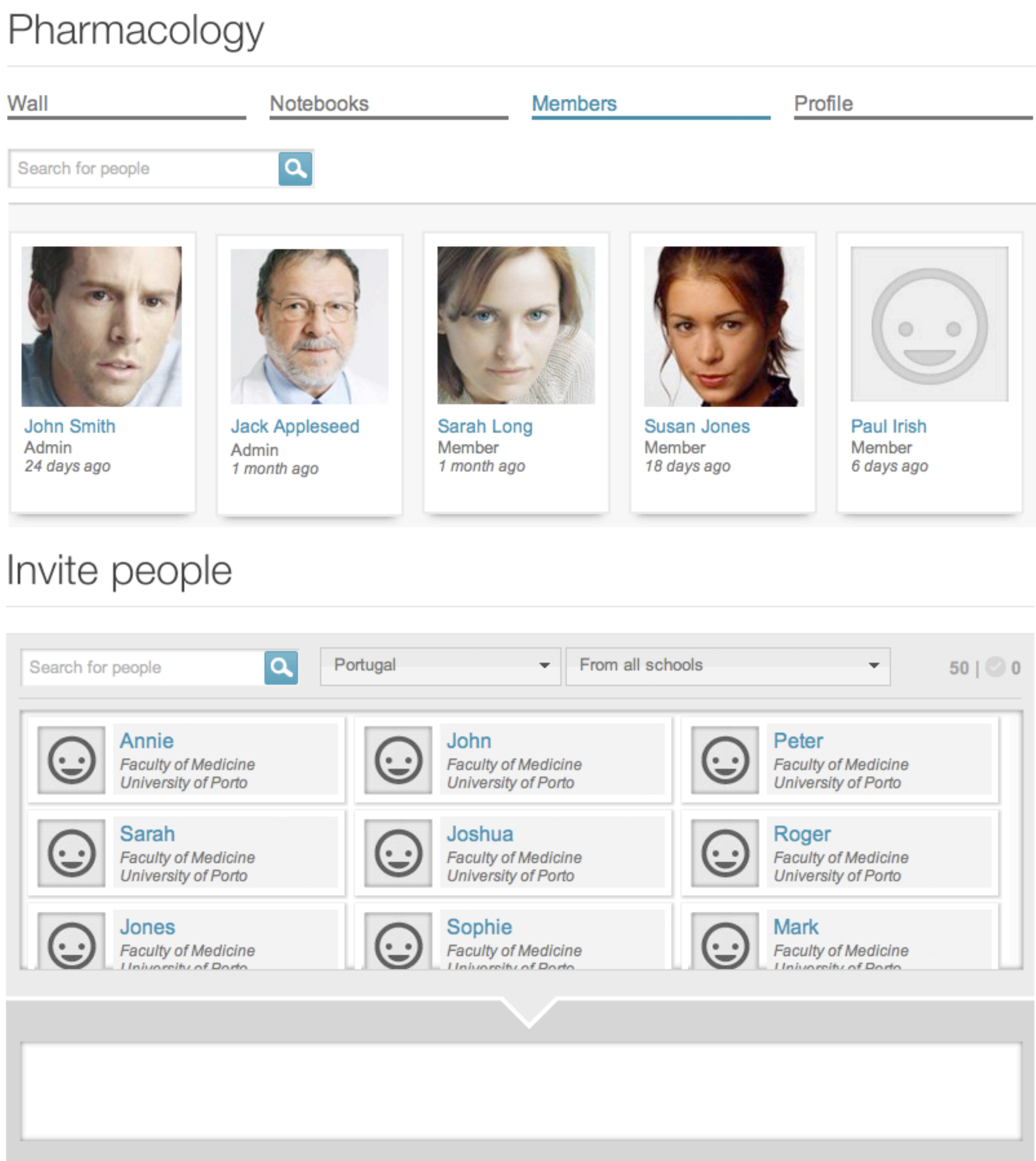

Figure 7- *Group* users. Members are shown on the first list. Administrators can manage users and they can additionally use the lower list to search and invite users to the *Group*.

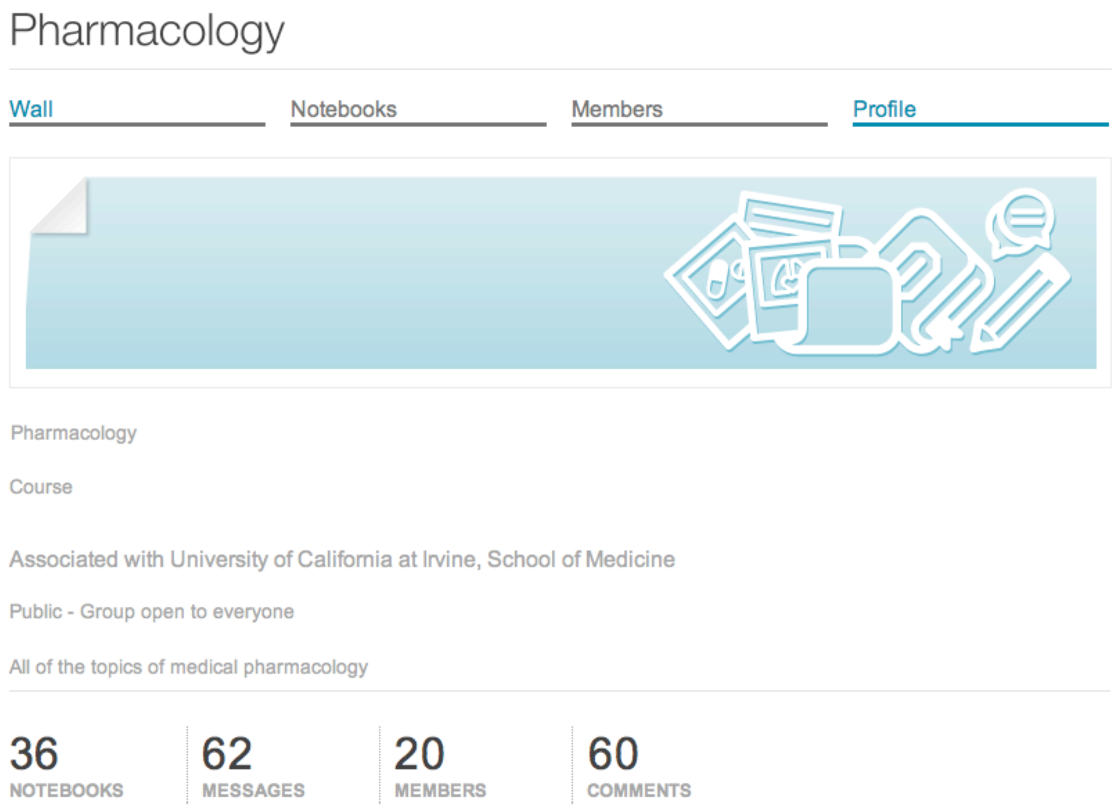

Figure 8 – A *Group* profile page. This page summarizes the *Group* purpose, content and activity. Non-member user can reach this page and ask for permission to join the *Group*

Notebooks

A *Notebook* section where users can access *Notebooks* from the groups they have subscribed was created. *Notebooks* were grouped into 3 sections for: (a) subscribed *Notebooks*; (b) archived *Notebooks;* (c) all user accessible *Notebooks*. Results for each section can be filtered by subscribed *Group* (Figure 9).

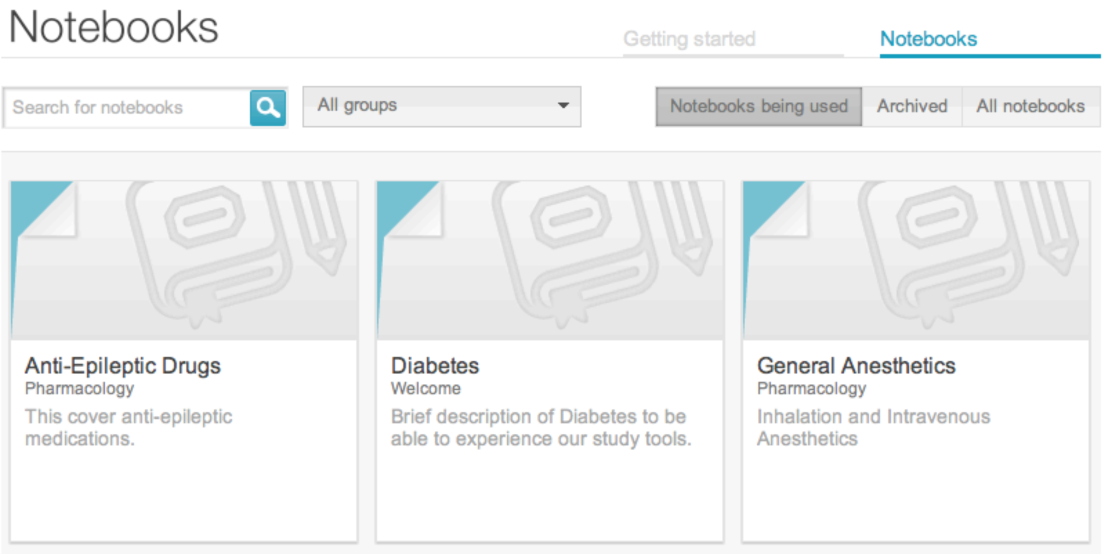

Figure 9 - *Notebook* list. *Notebooks* can be searched using the search bar and the *Notebook* status filters plus they can be filtered according to the subscribed *Group* selection.

Each *Notebook* has its own screen that shows information regarding the *Notebook* structure as well as personal and collective progress. It displays the total number of *Topics* and *Flashcards* that compose the *Notebook,* as well as the number of users subscribed and the number of sessions the *Notebook* has been studied by the user (Figure 10).

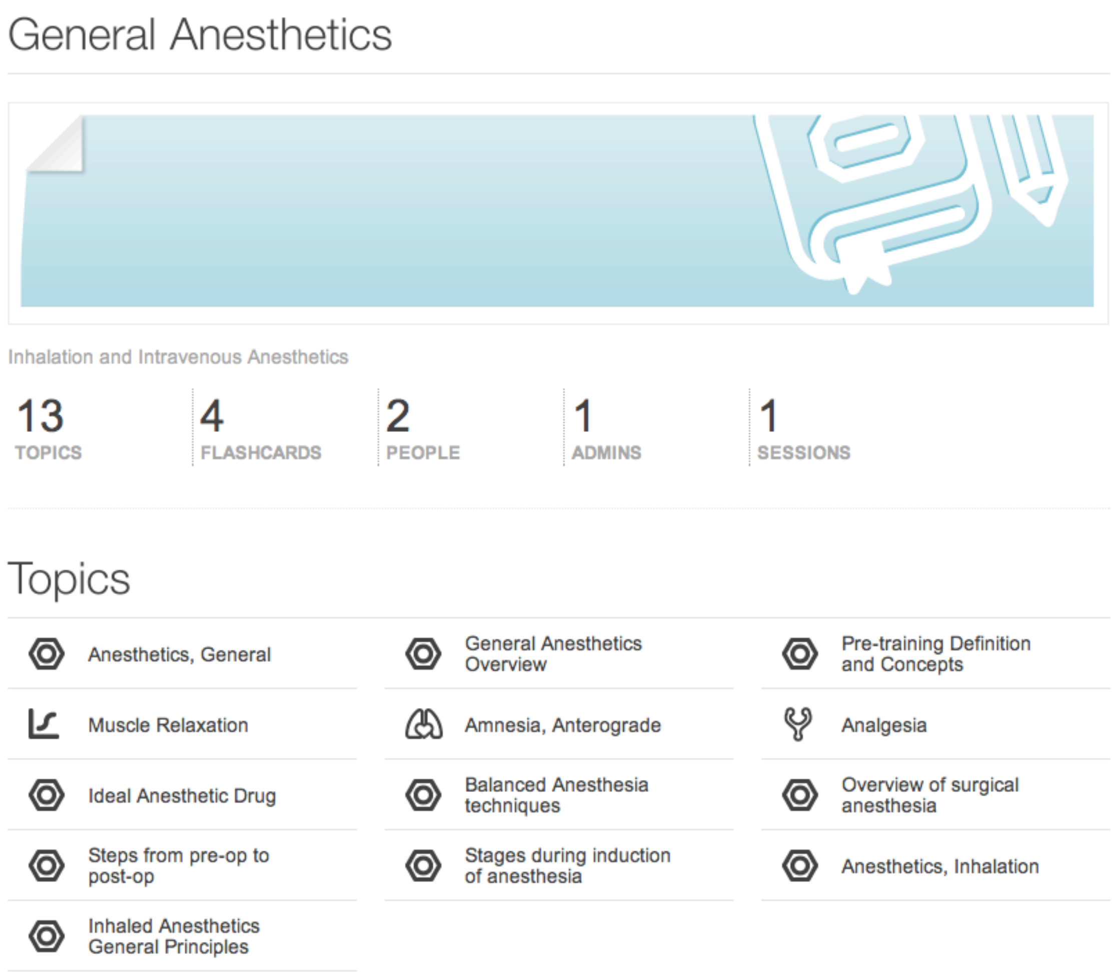

Figure 10 – The *Notebook* page header. Notebook content and usage are depicted as well as an outline of the *Topics* covered. Each *Topic* icon represents a type of topic.

This information is also displayed using a *Sunburst* info-graphic visualization from d3.js library [38] [39]. It allows the user to understand the relationships between *Topics* and sub-*Topics* as well as the relative size of each *Topic* based on the number of *Flashcards* each contains (Figure 11).

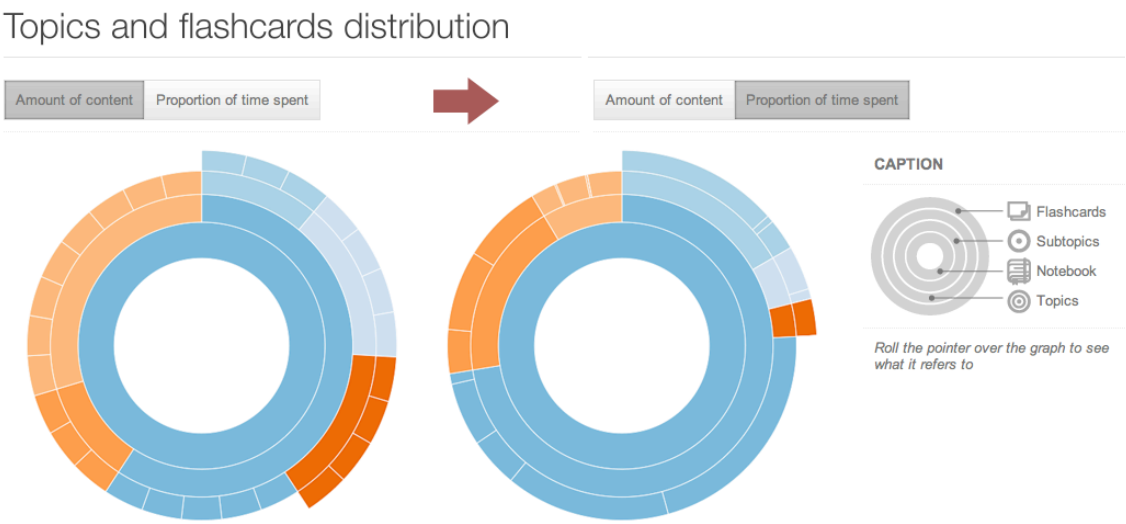

Figure 11 – The *Notebook Sunburst* chart representing *Topics* and *Flashcards* distribution. The toggle button switches the graphical configuration between relative content size (based on *Flashcard* count) and proportion of time spent studying each *Flashcard.*

Additionally, this chart can be adapted to reflect the proportion of time the student has spent on each particular *Flashcard*. In this context, *Flashcards* where most time was spent will grow and *Flashcards* where less time was spent will shrink.

Another section charts *CFK* per topic in a grouped bar chart. *Topics* are plotted on the *x* axis and *CFK* is expressed on the *y* axis. A set of bars represents the student CFK and the other set of bars represents mean *Group CFK* (Figure 12).

Finally a line chart to view *CFK* per *Quiz* session was developed. Sessions are plotted on the *x* axis and *CFK* is presented on the y axis. A line represents student performance and another represents mean *Group CFK* (Figure 12).

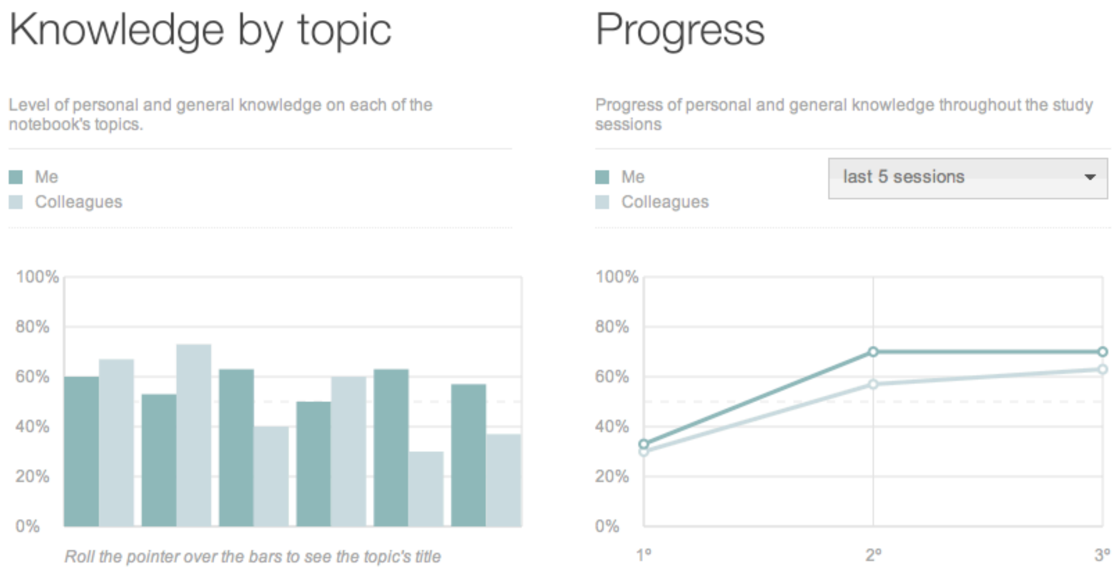

Figure 12 – *Notebook* performance charts. The diagram on the left depicts charts *CFK* per *Topic* in a grouped bar chart. The diagram on the right is a line chart representing *CFK* per *Quiz* session.

A single screen to allow search, addition and ordering of *Topics* to the *Notebook* as well as creation, addition and ordering of *Flashcards* was devised. This system also allows users to edit the *Notebook* simultaneously. Two separate lists for searched *Topics* and *Topics* added to the *Notebook*, which are accessible through tabs, were also created (Figure 13). Plus, a force-directed visualization built with d3.js to expose relationships between topics that could not be clearly expressed in nested-list views was implemented [38] [39] (Figure 14).

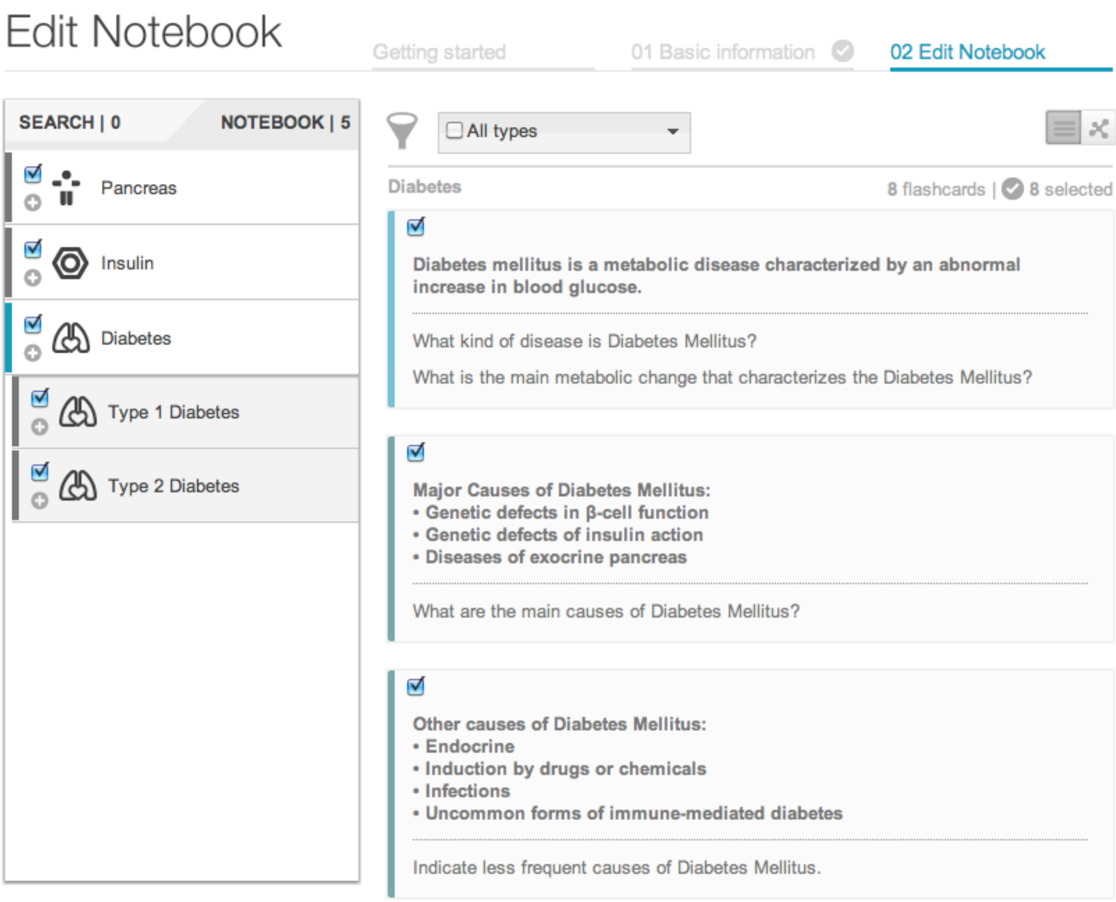

Figure 13 – The *Notebook* editing environment. *Topics* can be browsed on the left column on the search tab. *Topics* can then be checked in order to become part of the *Notebook*. Those *Topics* can be accessed on the *Notebook* tab next to the search. The right column will display *Flashcards* for the selected *Topic*. Checked *Flashcards* will become part of the *Notebook*.

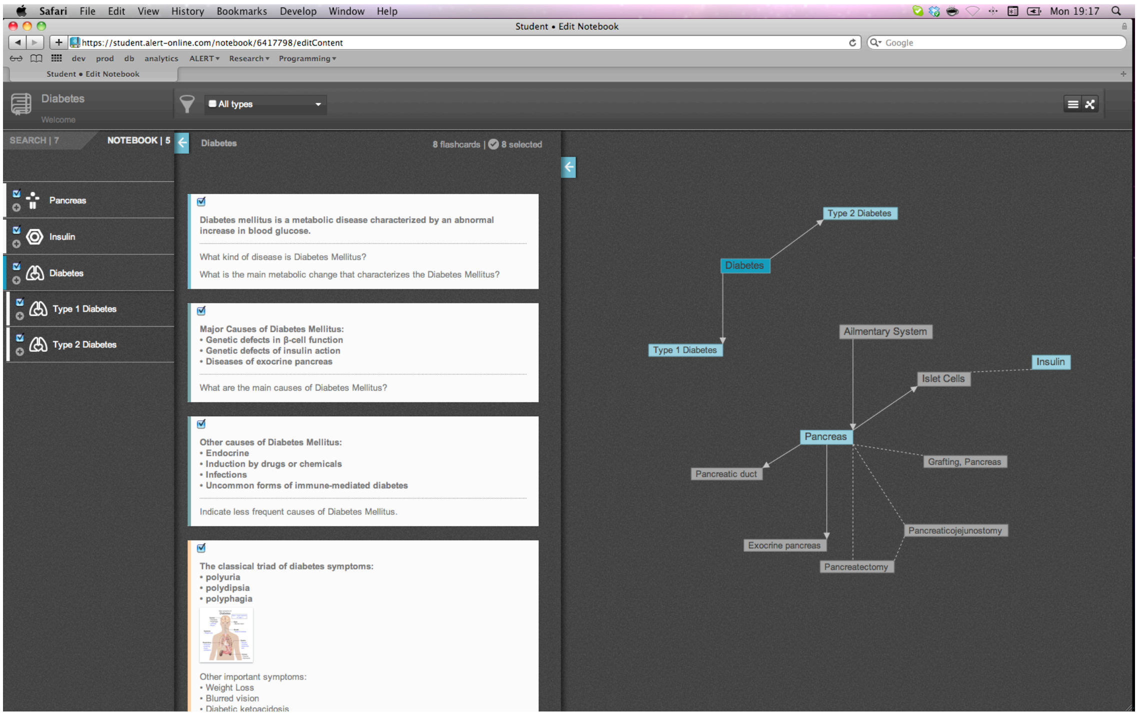

Figure 14 – *Notebook* full screen view. This view allows *Topics* to be visualized using both the nested-list and force-directed graph views. On the force-directed chart on the right, blue boxes correspond to the topics that compose this *Notebook*. Boxes in gray represent topics that have been searched for but still have not been added to this *Notebook*.

Study Mode

A *Study* mode where *Notebooks* can be studied on a learning oriented environment was created. This mode implements the *Topic* and *Flashcard* column visualization in a dark environment to improve focus on the content. A *Navigational Index* of *Topics* to aid positioning and navigation was implemented. All tools were created in collapsible menus, in order to allow removal of possibly distractive elements. For the same reason, all *Flashcard* actions are displayed only on mouse over. *Flashcards* can be flipped one at a time or altogether. (Figure 15)

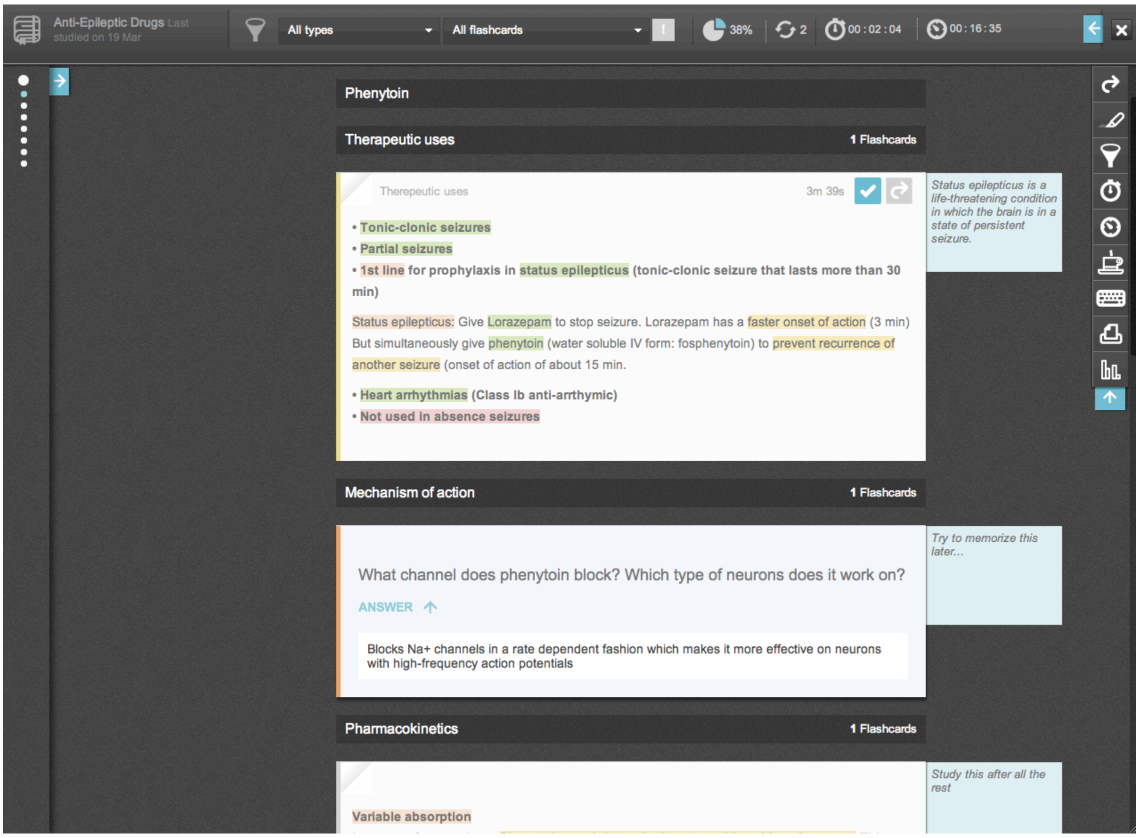

Figure 15 – *Study Mode*. The navigation bar on the left is in collapsed mode. The blue circle represents the current topic displayed in the *Flashcard* column. The top bar houses the content filters, progress status, the clock and the timer. On the right is the action bar. *Flashcard* column is represented on the center. *Topics* permeate the *Flashcard* column whenever they change. The first *Flashcard* is facing the front with study content, and the second *Flashcard* is facing backwards, showing *Questions*. The *Flashcard component* for the first *Question* is shown.

Each *Flashcard* has a button that sets a time lap and increments the time from that lap to the time already taken studying the *Flashcard*. *Flashcards* can also be marked for later by folding the top left corner. *Flashcards* marked as such will not be assessed in the *Quiz* mode. Additionally, *Flashcards* have a colored bar on the side that expresses *CFK.* (Figure 15)

Flashcards can be filtered according to *CFK* or by category. A timer can be set directly by clicking or by incrementing additional time from the options on the menu. A text highlighter is available using four colors that match the same four colors used to *CFK*. Each *Flashcard* has an attached note where students can write. The system also provides a way to create PDF documents from *Notebooks* that can then be printed. (Figure 15)

Additionally, all major actions such as highlighting text, taking notes and adding time to the *Flashcards* and flipping them, can be accessed through keyboard shortcuts.

On the header bar and bottom of the *Flashcard* column the student finds the statistics regarding the percentage of *Flashcards* studied, number of study sessions, time taken per session, total time spent and time spent last session. On the bottom, the student can also mark the *Notebook* as studied so that the system increments the number of study sessions by one and resets the studied *Flashcard* percentage. (Figure 15, Figure 16)

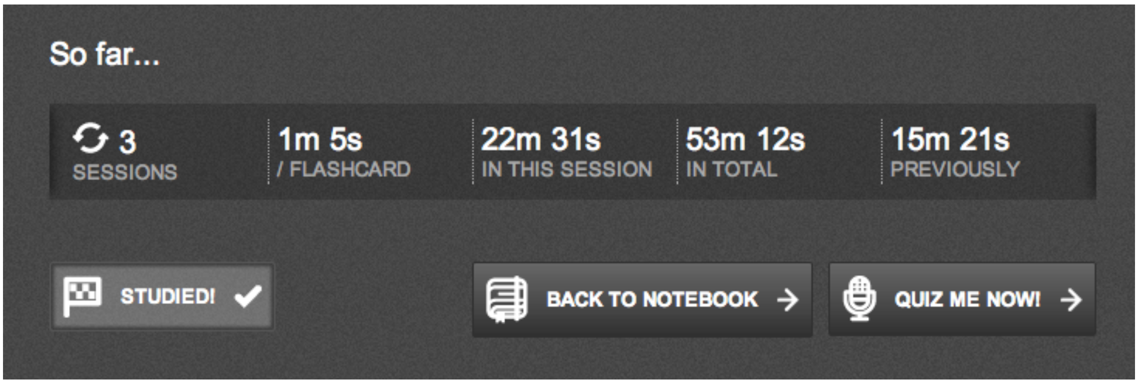

Figure 16 – *Study Mode* statics and actions on the end of the *Flashcard* column.

The system automatically pauses after two minutes of inactivity, either when the user leaves the window, or through a pause button on the options bar. The pause screen provides a clock that measures the time that the student has been on pause, and automatically brings focus to the window after ten minutes. When the user leaves the *Study* mode and then comes back, the system will automatically position the screen on the last studied *Flashcard* automatically.

Quiz Mode

The mode for assessment of *QPK* was built providing a minimum of interactivity to decrease the number of variables that may possibly bias assessment. The student is presented a *Question* at a time. The only action available is to show the answer. After selecting this option, the

Flashcard component containing the answer is shown along with a set of buttons used to grade *QPK* on a 4 level scale. The student also has the option of reporting the card to the administrators when inaccuracies are found. After the evaluation step, another card is shown. The system displays student progress and the number of *Questions* rated per grade. The time spent is also tracked and the pause system available. (Figure 17)

When the user finishes the *Quiz*, statistics about the time spent on each session are presented in addition the ones already stated (Figure 18). Furthermore, the student can review the *Flashcards* for the *Questions* with lowest *QPK*. Each *Flashcard* is shown under the respective *Question* with the answer *Flashcard component* highlighted (Figure 19).

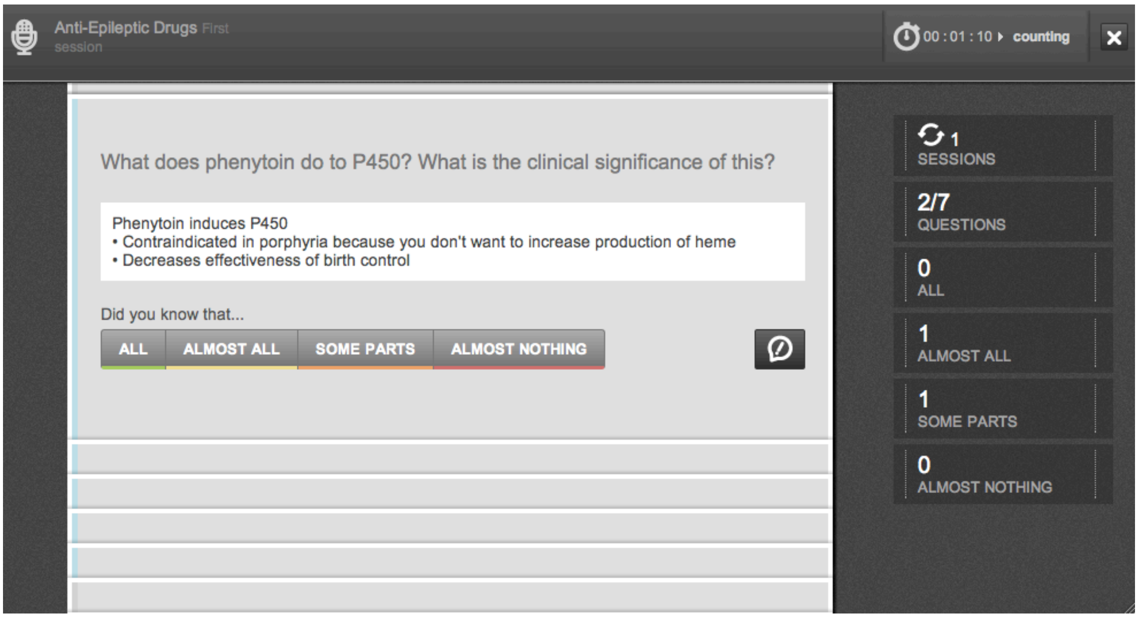

Figure 17 – *Quiz Mode*. A *Question* card is represented along with the answer. *QPK* is graded using the set of four buttons shown. The rightmost button allows the *Flashcard* containing this *Question* to be reported to *Group* administrators. The column on the right tracks student performance as assessment progresses.

Figure 18 – Quiz mode statistics. After *Question* cards have been answered, a set of statistics regarding time spent and performance are displayed.

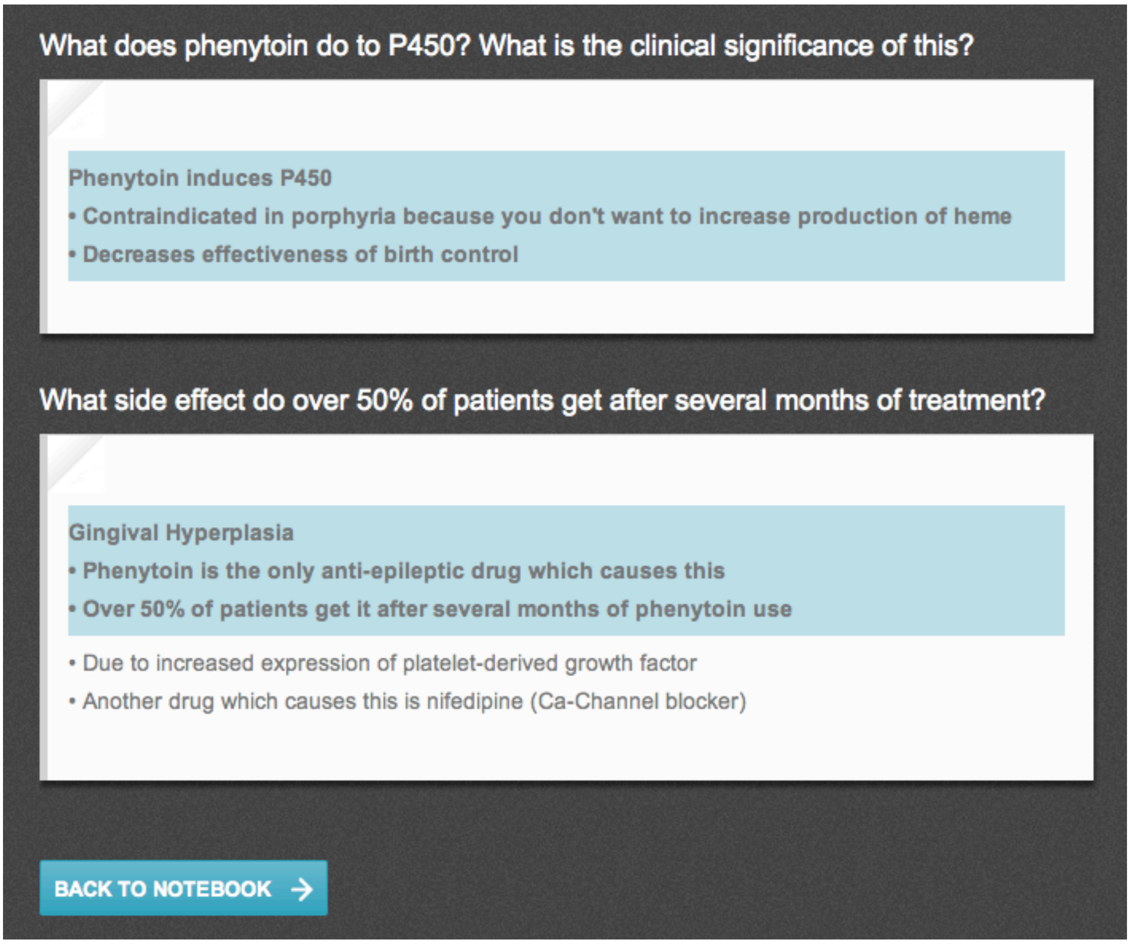

Figure 19 – Quiz mode *Flashcard* review. *Questions* marked as hardest can be reviewed in the context of the full Flashcard that is displayed below the *Question*. The answer *Flashcard component* is highlighted in blue.

System usability and adoption surveys

The score for all items on the survey regarding system usability and tool usefulness (Table I) showed means above 3 in both sessions. There were no significant differences between both sessions with exception of survey items 1, 4 and 14. Items 1 and 4 mean value increased while item 14 mean value decreased. Regarding the survey on willingness to adopt the system as a study tool (Table II) the mean of every item was approximately 3 (partially agree).

Table I – System usability and tool usefulness survey.

System usability and tool usefulness					
Nº	Item	Session	Mean	SD*	p
1	It was easy to study using the computer	1	3,21	0,69	0,04
		2	3,38	0,61	
2	The *Study Now* mode was easy to use and understand	1	3,68	0,52	0,06
		2	3,81	0,40	
3	The division of content using *Topics* and *Flashcards* was easy to understand	1	3,64	0,53	0,60
		2	3,68	0,47	
4	The division of Flashcards into *Facts*, *Details*, *Images* and *Questions* was easy to understand	1	3,60	0,58	0,04
		2	3,77	0,43	
5	The division of *Flashcards* into *Facts*, *Details*, *Images* and *Questions* helped to understand the key information to memorize	1	3,43	0,58	0,84
		2	3,45	0,72	
6	The information on the *Flashcards* was simple and clear	1	3,62	0,49	0,80
		2	3,60	0,54	
7	The *Flashcards* were presented in a logical sequence that facilitates learning	1	3,34	0,67	0,29
		2	3,43	0,65	
8	It was easy to find the *Flashcards* I wish to study using the *Flashcard* filters	1	3,38	0,61	1,00
		2	3,38	0,61	
9	The highlighter and the notes are useful features	1	3,66	0,64	0,41
		2	3,72	0,54	
10	The *Questions* on the *Flashcards* were easy to understand	1	3,34	0,73	0,37
		2	3,45	0,65	
11	The *Questions* were helpful to help me assess my knowledge about each subject	1	3,62	0,61	1,00
		2	3,62	0,53	
12	I could easily find the matching *Answer* to the *Question* in the *Flashcard Component* box.	1	3,53	0,58	0,20
		2	3,66	0,48	
13	The order in which the Questions were presented did not affect my focus on answering	1	3,34	0,70	
		2	3,32	0,69	0,86

* SD – Standard Deviation of Mean

Table II – Willingness to adopt the system as a reference tool.

Willingness to adopt the system as a reference tool			
Nº	Item	Mean	SD*
15	I think this system could be used in other basic science subjects	3,77	0,43
16	I think this system could be used in clinical science subjects	3,32	0,75
17	I see an advantage in using this system as a tool in my daily study	3,26	0,71
18	I think this system would allow me to obtain results similar or better than my average results while investing less time studying	2,96	0,83
19	I wish this system would encompass the content in the way I am taught at school	3,51	0,62
20	I would like to create content to take advantage of it using this system	3,40	0,71
21	I would like to collaborate in real time with my colleagues to build useful content fast	2,94	0,63
22	I would like to be able to print the notebooks from the system	3,74	0,57
23	I would rather use this system instead of my regular notebooks provided all the required content is available	3,11	0,84
24	I would rather use this system instead of lecture materials provided all the required content is available	3,19	0,80
25	I would rather use this system instead of the recommended bibliography provided all the required content is available	3,11	0,89
26	I would recommend this system to my colleagues	3,68	0,52

* SD – Standard Deviation of Mean

Discussion

The results obtained in this study demonstrate that overall the system responds to the issues raised even though there are particular aspects that need continuous improvement. To our knowledge, no other systems take such an approach to distribute materials and manage study. Other systems are only mentioned and contrasted in respect to specific features that display overlap.

Groups

The *Institution Groups* support localization of knowledge since each *Institution* can represent an isolate learning environment. Allowing created *Topics* and *Flashcards* within *Institution Groups* to be available to other *Groups* facilitates sharing within the *Institution*. This helps to reduce content redundancy since the same *Flashcards* and *Topics* can be reused over other *Groups*, without the need to create new material.

However, independent *Groups* are only visible according to the language the user has defined. Therefore, for instance, English users will have difficulty in subscribing Spanish *Groups*. This may become a hindrance in situations where English *Groups*, as a main spoken language, may become important references for other students from other countries that could eventually find useful material in those *Groups*. Even though this may decrease content sharing and increase redundancy at an overall level, we understood that focusing on the particular learning environment of each school would be a beneficial approach as it would reduce the exploratory component involved in the learning process and therefore increase value over student performance [23].

Notebook creation is only allowed within the context of *Groups*, preventing users to create their own personal *Notebooks* and *Flashcards*. This may decrease the level of tailored learning the system could provide to students. While such feature would be of great advantage to effectively address student needs, we understood that creating content on a user basis in the early phase of the project would lead to content duplication. Therefore, allowing content creation from within *Groups* avoids this problem since only a limited number of users can create and manage content that can then be distributed to a broader amount of students. This stimulates content reuse and promotes content sharing between courses for each Institution.

Notebook

The *Notebook* allows content to be created and reused in ways that match specific learning goals and can be reused with little effort to match other learning requirements. Because the system keeps track of individual information about the performance of each student over a *Flashcard*, reusability of *Flashcards* may not only increase learning material coherence within schools, but also allow students to use content they are accustomed along with *CFK*. They are this way in accordance to the definition of learning objects [40], abiding to the principles of stand-alone, reusability, interactivity and aggregation [14], which are further implemented through the *Notebook* entity.

Because *Flashcards* are small chunks of content, their use is supported by research in cognitive theory showing that human beings learn more effectively when content is presented to them in such a way [9]. Reusing *Flashcards* in different contexts along the curriculum can be beneficial according to cognitive load theories. Revisiting *Flashcards* to further deepen knowledge allows the usage of long-term memory schemata acquired on the previous contacts with such *Flashcards* and reduce the amount of elements that will be dealt with using working memory, thus reducing cognitive load and speeding the learning process [41]. Furthermore, revisiting is extended by refactoring of multiple *Notebooks* into summary *Notebooks*, that may be helpful to fulfill study requirements in a review phase, leveraging the same cognitive load principles [41]. Performance data for overlapping *Flashcards* can be used to optimize further study sessions in a new *Notebook* setting, once more subscribing the principles of learning object reusability, interactivity and aggregation [41].

Even though the technology and the principles of adaptive learning are well set, to our knowledge this approach is still a relatively new trend in e-learning [9].

The info-graphic charts allow the student to take action on their study sessions based on evidence of personal and *Group CFK*. There are however concerns in the interpretation of such information on charts regarding *CKF*, because *CFK* is derived from *QPK,* which is a subjective measure. Additionally, because *QPK* is computed from student self-assessment, it is prone to reflect both affective and cognitive factors and therefore may decrease the system ability to accurately tailor learning needs in situations that affective factors may play a main role [42].

Using the *Sunburst* chart that represents content distribution, students can easily understand how their time was distributed on the learning material, so that they may better plan further study sessions based and better manage time. However, for this representation, *Flashcards* should not be considered as fixed-size units. *Flashcard* size should be proportional to the size of its content. Considering *Flashcards* as fixed-size units may bias the representation of relative content size as well as the size computed by time spent.

Although being useful, these tools only provide visualization of static data sets and are still far from more dynamic interfaces that allow performance data filtering and segmentation implemented by other tools [20] [28].

The *Topic* browsing system using simultaneous list and force-directed visualizations allows the creation and cataloguing of content over a searchable interconnected mesh of *Topics* that express meaningful relationships. These combined representations may be as well suited for explorative learning approaches since it clearly exposes relationships between entities, thus fostering knowledge integration [43].

Study mode

The *Study* mode allows study in an adequate digital environment, which minimizes sources of distraction. The dark colors used on the interface contrast with the white *Flashcards*, creating focus on the area of interest. Combined with spaced lines with mean 70 characters in length and large window height these factors increase reading speed, comprehension, and reduce fatigue from screen reading [44] [45]. Additionally, the ability to hide tools in combination with the keyboard shortcuts allows the student to improve focus even more while still being able to make use of most tools. The possibility to filter *Flashcards* according to priority or type further allows study sessions to be objective-oriented by showing only content that meets individual needs. According to cognitive load theories, this approach may be useful to reduce intrinsic cognitive load as the learning process can be oriented in a simple-to-complex strategy and reduce extraneous cognitive load through minimizing splitting of attention over content that is not required for particular study goals [41] [46]. The *Navigational Index* of *Topics* combined with the *Notebook* progress meters provide a sense of position and progress, which can decrease extraneous cognitive load [41] as well and help to build motivation based on the visual feedback of progress [8] (Figure 15). Flipping the *Flashcard* column allows content-oriented and *Question*-oriented dynamic study environments that further tailor learning needs. Finally, the ability to resume study sessions from the point that they were last left also helps to decrease extraneous cognitive load by reducing the distance to the point of focus [41] [46].

Quiz mode

The *Quiz* mode is essential for the system to compute *CFK* and *QPK*. Because each *Flashcard component* may have more than one *Question*, the *Quiz* mode is able to show the *Question* for each *Flashcard component* with lower *QPK*. Not only it reduces memorization through mnemonics, but provides a means to assess knowledge using *Questions* that are most difficult tailoring memory retention needs [19]. This is also in accordance to the intrinsic cognitive load strategy of low-to-high fidelity tasks because as the student progress, *Questions* representing harder tasks will be preferentially selected [41]. However, the system does not take into account higher *CFK* or *QPK* to exclude *Flashcard components*, therefore each Quiz session will always go over all the material that composes a *Notebook*. This may difficult focusing on harder *Questions* since the system will not filter the content that has been successfully learnt. Moreover, the system does not take into consideration time spent on *Flashcards* to compute *CFK*, nor does it schedule tailored study sessions based on these inputs, as other tools allow [18] [19] [28]. Although the aim is to provide such functionalities, still, the only way to partially overcome these difficulties requires the student to mark *Flashcards* to study later; this increases *Quiz* value at the cost of manual management.

As mentioned, the way the user grades *QPK* is subject to affective factors that may decrease the beneficial effect of the system [42]. The goal is to deliver tools to objectively assess student knowledge in ways that can reflect performance in unbiased ways.

System usability and adoption surveys

Both surveys have shown that students generally agreed that the tools provided were useful and simple and were willing to use them as a privileged element for their medical education. Survey items 1 and 4 regarding studying online and the *Flashcard* structure showed a significant increase from the first to the second session. This may be due to competencies developed during the first session, that made studying online and understanding the *Flashcard components* better on the second session. Survey item 14 showed a significant decrease, but still within the partially agree range. On the first usage of the system the student realized the benefit it had over its previous learning experience. As the students became accustomed to the system, their perception of the acquired gain versus its previous experience that now considers experience of using the system led the students to feel less benefit from its usage. On the other hand it would also be possible that the benefit from using the system is maximal on the first study sessions and gradually decreases over time, therefore explaining the result.

Final remarks

Overall the application brings in a new set of tools that may be helpful to organize knowledge in meaningful ways [14] as well as to manage study sessions, based on personal performance to optimize study time. The system takes into consideration the main principles behind learning object design: (a) stand-alone; (b) reusability; (c) interactivity; (d) aggregation; (e) accessibility; (f) interoperability [14]. Assessment of student performance over content presented through this system and compare learning outcomes against other learning tools and methods will be studied in the near future. The development of these features is an important step into bringing evidence-based learning to students. Combined with tools to easily manage and share content, and to help guide study sessions, the system may be helping future physicians to meet the challenge of information management [4], instilling a culture of continuous learning, as well as providing the possibility to invest more time developing the other core medical competences outlined for XXI century physicians [1] [2].

Authors’ contributions

Tiago Taveira-Gomes

Conceptualization, analysis, design and development of the system

Literature research and paper writing

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Statement on conflicts of interest

The author of the study hereby states that there are no conflicts of interest in the present work. The system and the ways in which it helps to solve raised issues on medical education are described in a clear and unbiased way. The truthfulness or adequateness of all statements and considerations can be assessed by directly consulting the system, which is fully accessible and free of charge on the website at http://student.alert-online.com. The photographs depicted in the images are model photographs that ALERT® Life Sciences Computing S.A. has permission to be used for illustrative purposes.

Summary table

What was already known on the topic

- There is a recognized need to develop tools that are able to provide students with ways to achieve learning goals without consuming as much time.
- Students need tools that may help increase return from learning investment by retaining knowledge for longer periods, and ways to rapidly identify harder to retain materials and to swiftly re-memorize them.
- Students are in need of performance evidence based systems with which they can analyze personal and peer performance data and take insightful decisions regarding their study.

What this study added to our knowledge

- A system has been developed to allow content to be created and used in ways that match specific learning goals and reused with little effort to match variable learning requirements.
- This system gathers individual and collective performance data over studied content that is used to tailor learning process by guiding study sessions, pinpointing difficulties, managing and optimizing study time and filtering material based on objectives

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Anexos

Normas da revista International Journal of Medical Informatics

Guide for Authors

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• Structured abstract

• Body of the manuscript

• Authors' contributions

• Acknowledgements

• Statement on conflicts of interest

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