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Production and uses of e-learning tools for animal biology education at university

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Abstract
In many European universities, access to biology studies is non-selective and implies the enrolment of several hundred students who graduated from high school with a generally weak life sciences background. Teachers from the Biology Department of the University of Lille (France) are currently involved in a student-centred didactical project aimed to improve the attractiveness of animal biology using innovative e-learning tools. Members of younger generations are mostly used to visual approaches in learning, sometimes in contrast with the "traditional" educational methods. This is why the use of multimedia supports, available on different devices, can increase motivation and promote individual involvement in learning. We produced movies and interactive e-books describing the body plan and anatomy of organisms representative of the main Metazoan phyla. These free-access tools are used by students to prepare and review practical sessions. The learning outcomes include: (i) the visualisation of the dissection steps (technical know-how), (ii) identification of the main organs and understanding their relationships (memorisation), and finally (iii) the success of the evaluation (learning feedback). The integration of such multimedia tools, either in laboratory work or in lectures, contributes to an innovative approach in zoology teaching. The use of these information and communication technologies for education (ICTEs) has to be considered an original and useful means for helping learning, but it does not constitute a complete solution. This approach must be complemented with a solid and regular inductive instruction in the discipline.

Keywords: Undergraduate education, animal biology, active learning, e-learning, e-books

Introduction

Biology teaching in European universities is often offered in a non-selective manner to a huge number of students directly enrolled in undergraduate studies after high school. Arrival at the university constitutes a cultural shock for them, both in terms of memorisation of new vocabulary to learn and in terms of teaching methodology (vertical learning, imperative spelling, academic lectures, etc.). In addition, students come to the university without any learning strategies, especially in unknown disciplines. This is one of the main reasons for the failure rate in the first year of the bachelor degree. These problems are common in science, technology, engineering, and mathematics (STEM) disciplines, where instructors are challenged to improve student performance considering that they have diverse backgrounds, often based on varying social origins (Haak et al. 2011). To overcome learning problems, numerous pedagogical activities are proposed for STEM students either individually or in collaborative contexts through verbal questioning, written activities or peer discussions (Couch et al. 2015; Eddy et al. 2015). These difficulties are particularly acute in the life sciences, where students are rapidly faced with a huge amount of information including scientific terms. In addition, they often have trouble achieving scientific rigor and mastery of the native language in their oral and written productions.

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In France, STEM undergraduates may experience disparate modes of learning, from large lecture courses to small lab-based sessions, as in the USA (Freeman et al. 2014; Connell et al. 2016). Teaching in the experimental sciences requires basic and advanced face-to-face laboratory classes. This kind of approach generally involves high costs for the establishments in terms of chemicals and facilities. It constitutes a serious threat for STEM learning since universities have a tendency to reduce practical classes to control the costs of education. At the University of Lille (France), most of the curriculum of the first year of the bachelor's (B.Sci1) in life sciences is at present based on traditional academic lectures in large classes of about 128 students grouped in an amphitheatre. This didactic approach appears to be the best way to disseminate a large amount of information to hundreds of individuals and permits the university to contain education costs. Although enrollment in the B.Sci1 in life sciences is high, with an average of 680 students/year, multiple-choice exams are poorly utilised and great attention is paid to the assessment of editorial (native language proficiency) and experimental skills (30–40% of practical work, done in laboratory classes of 30–32 students). Undergraduates' prior experience in life sciences is generally low, especially in animal biology, considering that this discipline is so far poorly developed during high school. Bachelor's teachers are also subjected to the didactic challenge of giving students the scientific basis and inform them on zoology in a short time (six-month or in some cases annual courses). The objective is to provide, through academic lectures and practical sessions, the necessary knowledge and experimental skills in animal biology and systematics (mainly of Protostomes and Deuterostomes). Student performance could be enhanced if instruction supports and assessments adequately provided learning tools and met didactic objectives (Osueke et al. 2018). In this paper, we focus on an active learning approach that engages undergraduate students in life sciences to prepare each practical session with digital tools before the face-to-face class time. This kind of approach during the first year of a bachelor's degree in biology was reported to improve student performance by a range of 6–16% (Michael 2006; Freeman et al. 2007, 2014; Armbruster et al. 2009; Dupuis et al. 2013; Fraser et al. 2014; Stephens 2017; Hacisalihoglu et al. 2018). In addition, such integration of active learning in biology education helps students to acquire conceptual understanding and scientific thinking skills (Deslauriers et al. 2011; Freeman et al. 2014). Nevertheless, to our knowledge, little data is available about student-centred active learning to prepare for experimental sessions by using e-learning tools. This kind of practice is so far poorly developed throughout European academic institutions.

Some supports are currently available for medical instruction where it has been observed that e-learning modules, weekly discussions and YouTube educational videos increased student engagement, confidence and appreciation of academic principles and skills (Chapman et al. 2015). In addition, e-learning in medical instruction gives greater educational opportunities, enhancing faculty effectiveness and efficiency. It also ensures the alignment of new tools in an educational and economic context (Frehywot et al. 2013). Hybrid learning strategies could also be beneficial for nurse education. The majority of students appreciated alternative teaching approaches, notably videostreaming of physiopathology cases, but they also highlighted the importance of maintaining significant face-to-face time with lecturers (McKinney & Page 2009). Finally, the association of classic academic and non-attendance-based teaching, generally defined as blended learning, has been proposed as a very effective strategy for teaching human anatomy (Pereira et al. 2007). As described, although a certain amount of digital media on biology exists for medicine students, these kinds of resources are not available on the web for zoology learning. For these reasons, animal biology teachers at the University of Lille have developed a series of multimedia supports for bachelor's students to promote learning of this discipline. By watching high definition (HD) movies and working with interactive multimedia textbooks, students acquire techniques to reproduce for dissections, anatomy skills and competencies to compare metazoan body plans within an evolutionary and phylogenetic framework. This student-centred didactical project aimed to improve the attractiveness of animal biology using innovative digital resources. Members of young generations are mostly used to visual approaches in learning, sometimes in contrast with the "traditional" educational methods. The basic idea of this project was to propose the use of novel multimedia supports, available on different devices (computers, tablets or smartphones), to increase motivation and to promote individual involvement in learning. In addition, this approach partially addresses the constraints created by an increasing number of students and a decreasing academic budget, permitting universities to contain the cost of classroom instruction while valorising distance-learning strategies. We decided to focus this project on practical laboratory work and proposed movies and interactive e-books for each face-to-face class covering main metazoan models (https://pod.univ-lille1.fr/video/2973-supports-multimedias-pour-les-travaux-pratiques-de-biologie-animale/). The goal was to provide for each session the theoretical knowledge and experimental skills to acquire during a period of instruction of two weeks. Learning outcomes include different steps: the visualisation of dissection protocol gives the students technical know-how, the description of the anatomy by schemes and keys improves memorisation of organ names and relationships, and, finally, revision of the support material before evaluation is useful for learning feedback. This project was conceived with the help of the educational designers of the EdTech & Digital Pedagogy Department of the university. To evaluate the effectiveness of the project, we provided a 25-point questionnaire to our bachelor's students (n = 170) to ask them how they used these tools for studying animal biology and to obtain their overall opinion on the usefulness of these multimedia supports for their personal learning in the discipline. Results of the survey indicated that the available movies and e-books are largely utilised and appreciated by students in terms of quality and value. This positive feedback encourages us to proceed with producing and developing such tools for zoology learning.

Materials and methods

Video production

We made a series of eight movies describing the body plan and the detailed anatomy of animals representative of some metazoan groups (molluscs, insects, echinoderms, tunicates, teleosts, birds and mammals). These movies, produced in HD, are divided into 3–5-minute chapters illustrating the morphology of the animal and its main organic systems (digestive, circulatory, respiratory, reproductive, excretory, etc.). For the optimal utilisation of the 16:9 format, the screen is occupied by a main and a secondary window, alternately displaying filmed sequences, drawings or anatomical details (Figure 1). Images are supplemented by legends, schemes, macrophotography pictures, electron microscopy captures, and two-dimensional (2D) and three-dimensional (3D) animations showing organ structures and relationships. All the movies were made in French and some of them also exist in English for students in the bilingual programme

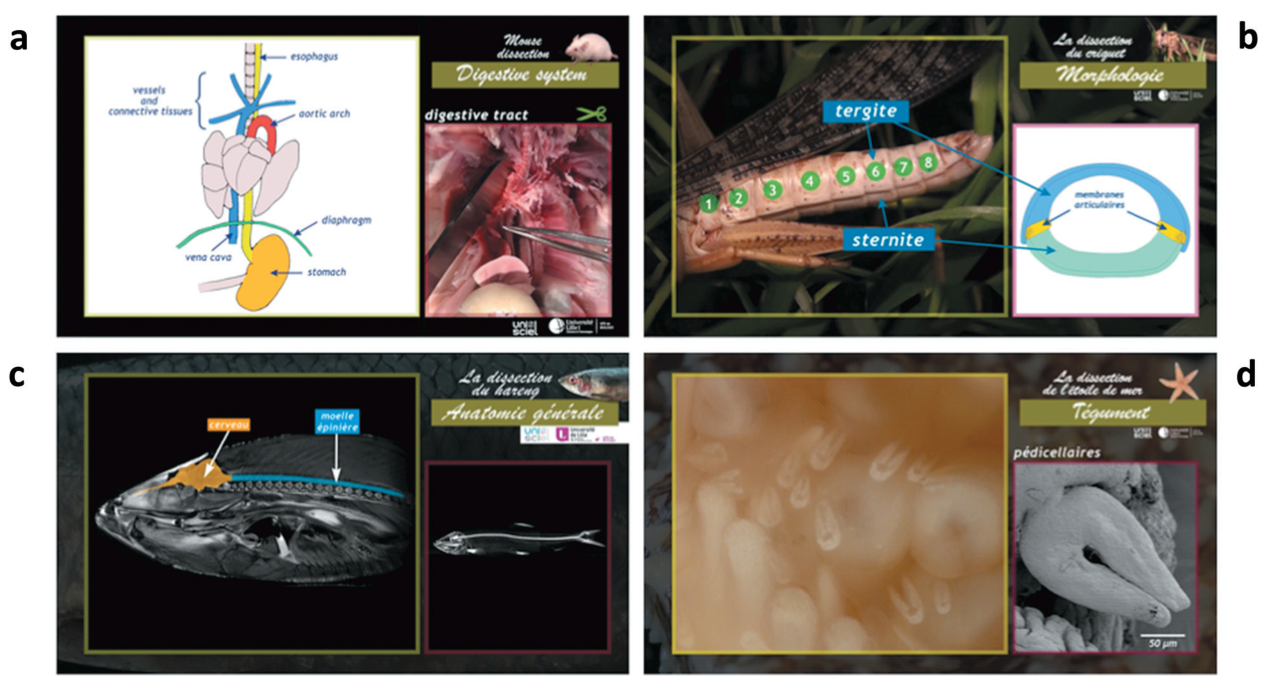

Figure 1. Screenshots from animal biology movies. Images are taken from videos on (a) mouse, (b) locust, (c) herring, and (d) starfish dissections. They show some examples of the utilisation of the 16:9 space split into two parts containing (a,b) video sequences and schemes, (c) medical imaging (computed tomography or Nuclear Magnetic Resonance), and (d) macro photography or scanning electron microscopy pictures. As an example, (a) shows a screenshot from a movie in the English version.

of our bachelor's degree in life sciences. The English version was also conceived to make these tools available to English speakers worldwide. The movies were entirely conceived by animal biology instructors, who also wrote the scenarios and the text for the voice-over, and who made the drawings. Multimedia engineers from the university performed shooting and film editing. Image capture and shooting were done with a Canon EOS 7D camera. Film editing software used was Final Cut Pro or Adobe® Premiere Pro CS6. The drawings were made with Adobe® Illustrator CS6; 3D animations were produced by 3D medicus (3Dmedicus.com). Movies are made available on a website dedicated to the whole project (http://photo3d.univ-lille1.fr/biologie/index.html), on the Université des Sciences en Ligne, (UNISCIEL) web site (http://www.unisciel.fr), on the scientific video channel CanalU (https://www.canal-u.tv), on the university's didactical podcast server (https://pod.univ-lille.fr/biologie-animale/) and on YouTube.

Multimedia textbook production

In association with the movies on dissections described above, we made several interactive multimedia e-books to be used by students for preparation and revision of laboratory sessions. These documents contain pictures, short movies, written text, hyperlinks and several interactive widgets to illustrate the work to be made during the lab session (i.e. dissection protocol), or other contents (Figure 2). To create these e-books, for each animal the authors used short sequences and drawings taken from the corresponding movies as well as pictures collected during the shooting but not used for film editing. Special sections in each chapter are dedicated to experimental protocol, indicating instructions and practical tips for organ dissection. These supports, entirely designed by teachers, were made using iBooks Author, a free program distributed by Apple. Their export and dissemination can be done in iBook format, compatible with all Apple devices, but also in a pdf version for PC or Android users. In the latter case,

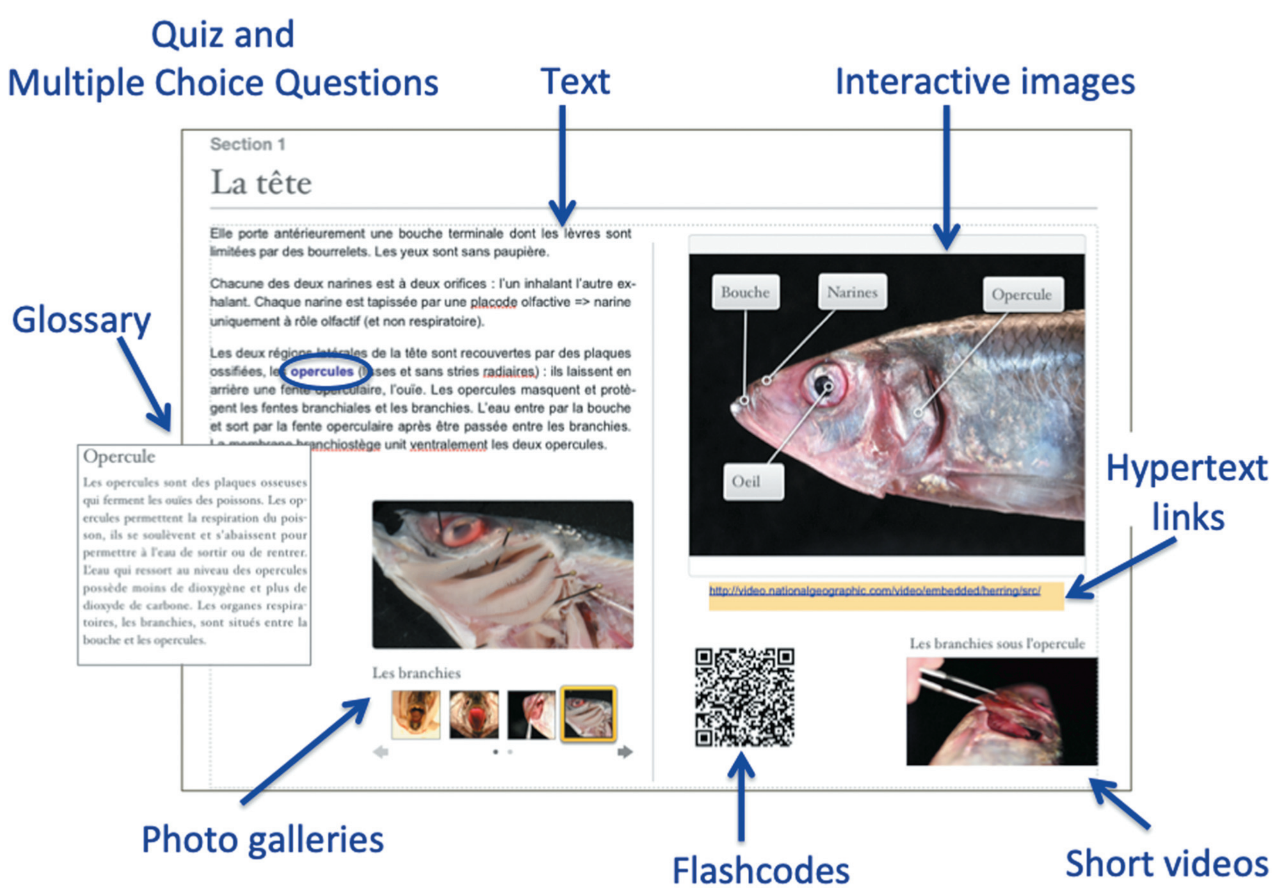

Figure 2. Example of e-book for practical sessions in animal biology. The picture, customised from the digital textbook on herring anatomy, illustrates the potential of these interactive tools. Some of the available widgets are displayed.

interactivity is strongly reduced since the software was not conceived for these types of devices. As indicated for the movies, these e-books are currently available in French, but English versions are being programmed.

Context and learning objectives

Digital supports described here are regularly used by about 700 undergraduate students taking the animal biology unit in the first year of the bachelor programme in life sciences at the University of Lille, a public institution. This unit consists of lectures (32 h/semester) complemented by practical sessions (18 h/semester). This unit belongs to a major scientific panel of disciplines also including cellular biology, physics, mathematics, general and organic chemistry, integrative biology, plant biology and animal physiology. Courses are taught in French, with the exception of a bilingual education course for two selected groups of 32 students having tutorials and practical laboratory work in English. The context tested here comprised six sessions of practical work on animal body plans, covering models such as herring, mouse, chick, locust, squid, mussel, starfish, ascidian and several examples of cnidarians, flatworms and annelids. This laboratory work is done by a group of 30–32 students and two teachers, with 3 h/session.

Learning objectives are clearly specified both in the videos and in the e-book/pdf supports. One of the main objectives of these tools is to further illustrate with images and schemes the anatomy of the different groups of animals described during academic lectures. Indeed, students are expected to acquire a good knowledge of animal anatomy and body plans together with a good technical grasp for handling dissection tools. They completed three distance-learning steps before each practical session: (a) review theoretical knowledge on phylum bauplan and systematics described during lecture courses; (b) watch a video describing dissection protocol, location and identification of organs (loading from pedagogic platform or YouTube); (c) read an e-book with written explanations and supplemental data (photo gallery, exercises to promote autonomous learning, quizzes). During the practical session, teachers showed the whole movie or some selected sequences to specify some crucial steps of the dissection, and provide complementary information on animal anatomy.

Questionnaire design

A questionnaire, including 24 questions plus one free text area, covering several objectives (Table I), was submitted to the students through the Moodle platform. They were given 3 weeks to answer anonymously. The questionnaire was addressed to first- and second-year bachelor's students, the latter having used the digital supports 1 year earlier. For each question on qualitative aspects, students were able to choose an answer from among several items. The student could then choose boxes that suit him or her. The sum of all the answers for all items is taken, then the share of choice of this or that item is calculated as a percentage on this sum. As an example, if answers a, b, c, d and e were chosen 111, 134, 64, 28 and 26 times, respectively, the percentage was calculated on the basis of the total of the 363 choices (a = 30.5%, b = 36.9%, c = 17.6%, d = 7.6% and e = 7.1%).

Results

Use of the digital media

The movies and multimedia textbooks here presented are made available on the pedagogic platform Moodle Lille. These supports are used every year by about 700 undergraduate biology students and 20 teachers. To give an idea of the high level of use of these supports on Moodle, the movies describing herring and mouse anatomy, in the period September–December 2018, were viewed 2089 and 2501 times, respectively, by 706 students enrolled in the first year of the bachelor's in life sciences. This distance-learning approach permits our students to use all these supports at any time to prepare their practical work sessions and to review for learning evaluations and exams. The aim of these resources is to provide for each animal model the theoretical knowledge (anatomy, organisation, vocabulary, etc.) and the experimental skills (dissection protocol) that are needed. Students are supposed to watch the movies and carefully read the e-books during a period of a minimum 2 weeks preceding the lab session. Each action (technical gesture) to be performed by the students is detailed in the movies by images and voice-over. Dissection steps, including the indentification of organs and their location in the animal body as well as their physiological role, are described in the movies and in the multimedia textbooks. During each practical session, all these actions could therefore be evaluated throughout the semester, as well as during the final exam (i.e. measurable goals). Assessments are based on (a) a short theoretical test (10 minutes) done at the beginning of the work session, (b) the capacity to reproduce techniques in order to present the body plan, and (c) a scheme or an observation drawing with legends made at the end of the dissection. We expect students to be able to mobilise knowledge (description,

Table I. List of topics and objectives of the questionnaire submitted to the students. The aim of the different groups of questions was to collect student feedback on the use and the appreciation of digital multimedia supports.

Topics		Number of questions	Objectives and context
Internet connection/access		3	At the public University of Lille, in sciences and technology, 48.4% of our students have a scholarship; 44% belong to a favoured socio-professional category. Not all students have a computer or a telephone with Internet access. Moreover, one should also consider equipment prices (trademarks).
Homeworking methods		3	These questions aimed to estimate whether "paper" supports were still used by this generation for learning and reviewing, or if students had completely moved to digital supports.
Videos usage	Before practical sessions	1	Questions were asked about both supports (video, e-book/pdf) and their personal methods. These questions are intended to separate upstream, face-to-face, and downstream learning.
	During practical sessions	1	
	To review practical sessions	1	
	Personal interest, advantages	2	
e-books/pdf usage	Before practical sessions	1	
	During practical sessions	1	
	To revise practical sessions	1	
	Personal interest, advantages, disadvantages	6	
Autonomy during practical session		1	Establish whether video and e-books/pdfs improve students' autonomy during the session.
Opportunity to extend videos and e-books supports to other experimental units		1	B.Sci1 in life sciences includes up to 40–50% of experimental sessions.
Student personal comments (free text)		1	The free text was optional. The proposition was to describe how students learned and to give suggestions to improve the digital multimedia supports.
Students' ranking of favourite videos		1	These questions were asked to collect the feelings and personal opinions of students. Pedagogical aspects were not considered here.
Ranking of favourite e-book/pdf		1	

physiology) and to reproduce adequate techniques for each animal phylum, and also to be able to compare the groups according to their evolution and phylogeny.

Learning feedback

To assess the utilisation of the dissection movies and associated e-books, we distributed to the students a 25-question survey targeting the use of these supports. We received feedback from 146 and 24 first- and second-year bachelor's students, respectively. Some questions concerned the methodology used for studying the discipline. During high school, students generally summarise on review sheets the most important contents of the different units. Most of them continue to apply the same method during the bachelor's for studying the different STEM disciplines, including animal biology. The act of handwriting and summarising the contents of academic lectures and practical sessions assists with their comprehension and memorisation. We wanted to quantify the use of paper supports (printed and/or handwritten notes) vs. digital supports (slideshows, e-books, videos) available on the pedagogic platform Moodle (Figure 3(a)). Results indicate that some undergraduates prefer to use only paper supports (16.8%), while around half of them (53.6%) base their learning on both paper and digital supports. Interestingly, 24.4% of our B.Sci1 students enlarged the panel of learning sources to "classical" biology books. A small percentage (4%) affirm learning exclusively using Moodle and other web sources. For preparation and review of practical sessions, in particular, half of them (50%) print out screenshots from dissection movies and paste them on paper sheets, completing the images with customised notes and comments (Figure 3(b)). Other questions concerned the use of digital tools before, during and after the practical sessions, e.g. for exam reviewing (Figure 4). The main questions asked were regarding (i) whether instructions were clear enough about practical learning outcomes, (ii) how students use the information or videos to study and (iii) why students find the information or videos helpful.

Results indicate that almost all of them watched the movies (94.6%) and read the multimedia textbooks (93.9%) before the lab sessions. Indeed, many students accessed these digital tools the day before (movies and e-books 39.4% and 39.3%, respectively) for the first time or for a final review (Figure 4(a,b)). Around half of them consider these supports useful to identify the different organs of the animal (48.1%) or to anticipate dissection techniques (50%). During practical sessions, undergraduates watch the movies (54.1%) or re-read the textbooks (51.8%) on their tablet and smart phone devices. Others do not use movies (39.4%) or e-books (23.5%) during the practical work and prefer other customised supports (6.5% and 24.1% for videos and e-books, respectively) (Figure 4(c,d)). A third part of the questionnaire concerned the use of digital resources for reviews before the final examinations held at the end of the semester. For this evaluation, students have to replicate completely

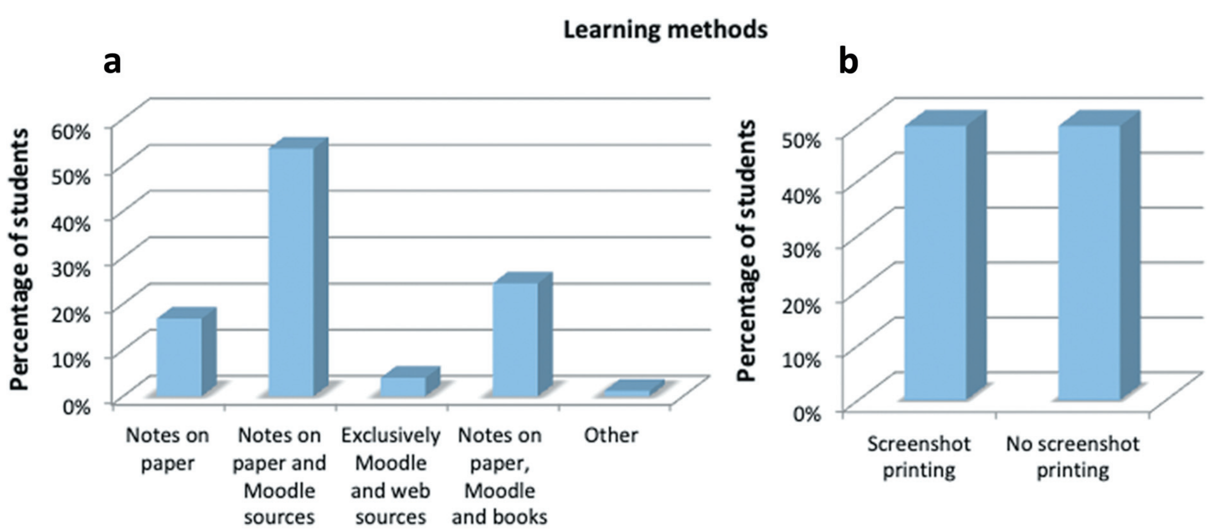

Figure 3. Learning methods. Histograms (a) indicate the percentage of utilisation of different supports to review academic lectures and practical session contents. (b) Half of the students printed images issued from movies and integrated them into customised notes for reviewing. The x-axis labels correspond to the questions asked in the questionnaire. For graph (a), multiple answers were accepted among the options proposed. The percentage calculation strategy for this kind of qualitative questions is described in the Materials and methods section.

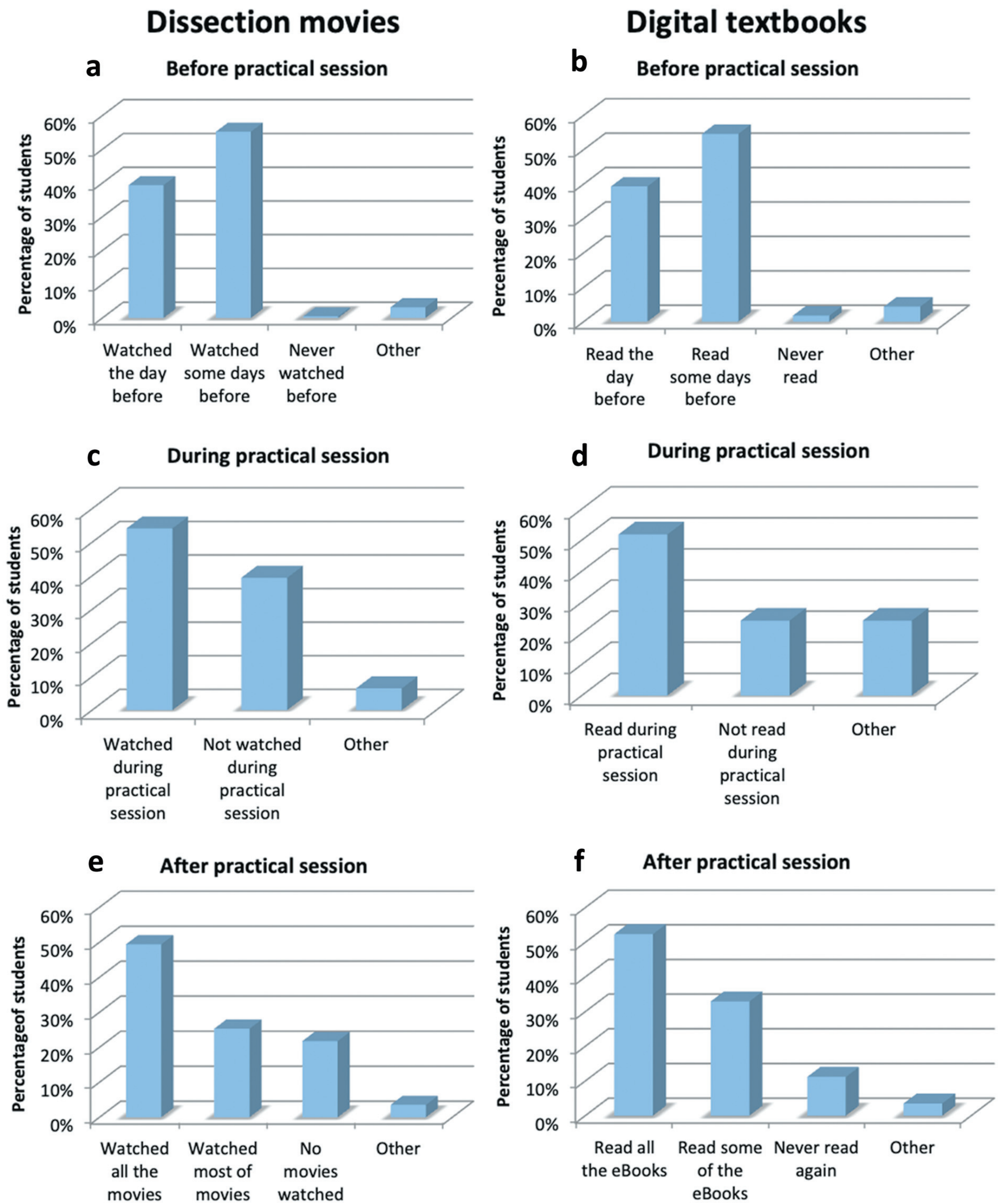

Figure 4. Utilisation of movies and e-books for active learning in animal biology. Histograms show the percentage of student using these tools (a,b) before, (c,d) during and (e, f) after practical sessions. The x-axis labels correspond to the questions asked in the questionnaire. For graphs (a and b), multiple answers were accepted among the options proposed. The percentage calculation strategy for this kind of qualitative questions is described in the Materials and methods section.

independently one of the dissections they had already performed and answer questions about animal anatomy and organisation plans. To prepare for this final exam, undergraduates generally watch again all (49.4%) or most (25.3%) of the movies (Figure 4(e)), and find that they are useful for remembering organ names (43.6%) and dissection protocols (49.7%). A small number of students do not use any of these supports for review (3.5%) and consider them useless for exam preparation (0.5%). Similar results were obtained for the use of e-books: they are generally entirely (52.4%) or partially (32.9%) read by students, but some students (11.2%) never read digital textbooks for final exam review and prefer to use other sources (3.5%) (Figure 4(f)).

We compared the review periods during the semester with the number of daily views of videos on Moodle. Sessions concerning herring and mouse dissections were selected as representative of the practical activities. Figure 5 shows the viewings of these movies over the period September–December 2018. During this time frame, the two laboratory activities occurred one after the other, each covering a 2-week period. The first peak of connections for each activity corresponds well to the days preceding the practical sessions. Within each 15-day period it is possible to distinguish three viewing peaks that strictly correspond to the schedule of practical sessions for our 23 groups of students. This confirms the fact that most of them systematically watch the movies the day before the practical work. Later in the semester, a new period of high frequency of connections is visible, showing the same pattern of three peaks and matching with the days of final examinations. The convergence of viewings of both movies during this second period can be explained by the fact that for the final exams, students are supposed to be familiar with all the dissections made before and can be asked about any of the observed models. Similar graphs were obtained for the practical work concerning the study of the other animals (data not shown).

We also investigated how undergraduates use digital textbooks: some of them take notes directly on the printed version of the document, merging the information with that received during academic lectures (53.6%). Also, although many students appreciate classic paper documents used for the study of other disciplines (21.8%), most of them prefer digital supports as well, in e-book (29.4%) or printed pdf (42.9%) format. This choice is linked to the spatial organisation of the document (30.2%) and the quality of images in term of colour, sharpness and relevance (36.4%) (Figure 6(a)). The aesthetics of these documents is appreciated by 25.4% of the students. Interestingly, they find these e-learning tools a new way of viewing the practical work in animal biology

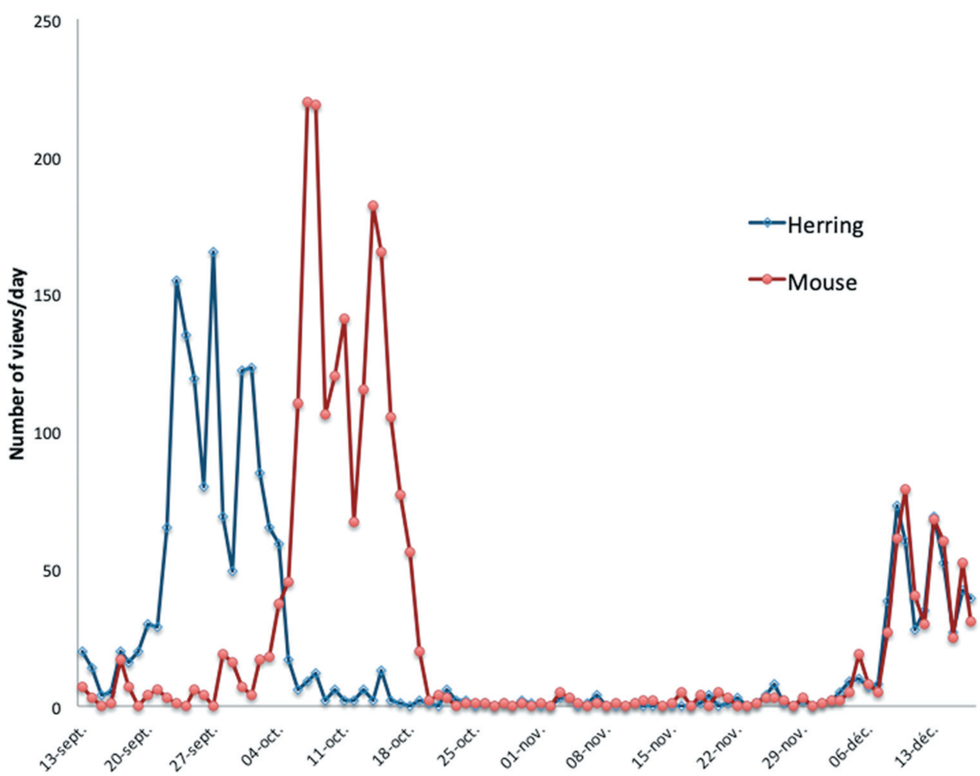

Figure 5. The graph shows the number of views/day of the movies on herring (blue) and mouse (red) dissections. The period analysed covers the weeks from the beginning of the animal biology teaching until the end of final examinations for practical work.

with respect to the other disciplines (17.4%). They consider the use of digital textbooks an opportunity to go deeper in their studies through the availability of photo galleries and hyperlinks (7.6%), or a way to open their mind to new aspects of animal biology (7.1%). The interest in these documents (Figure 6 (b)) also relates to their decreased environmental impact since no paper is used (18.1%), the reduced

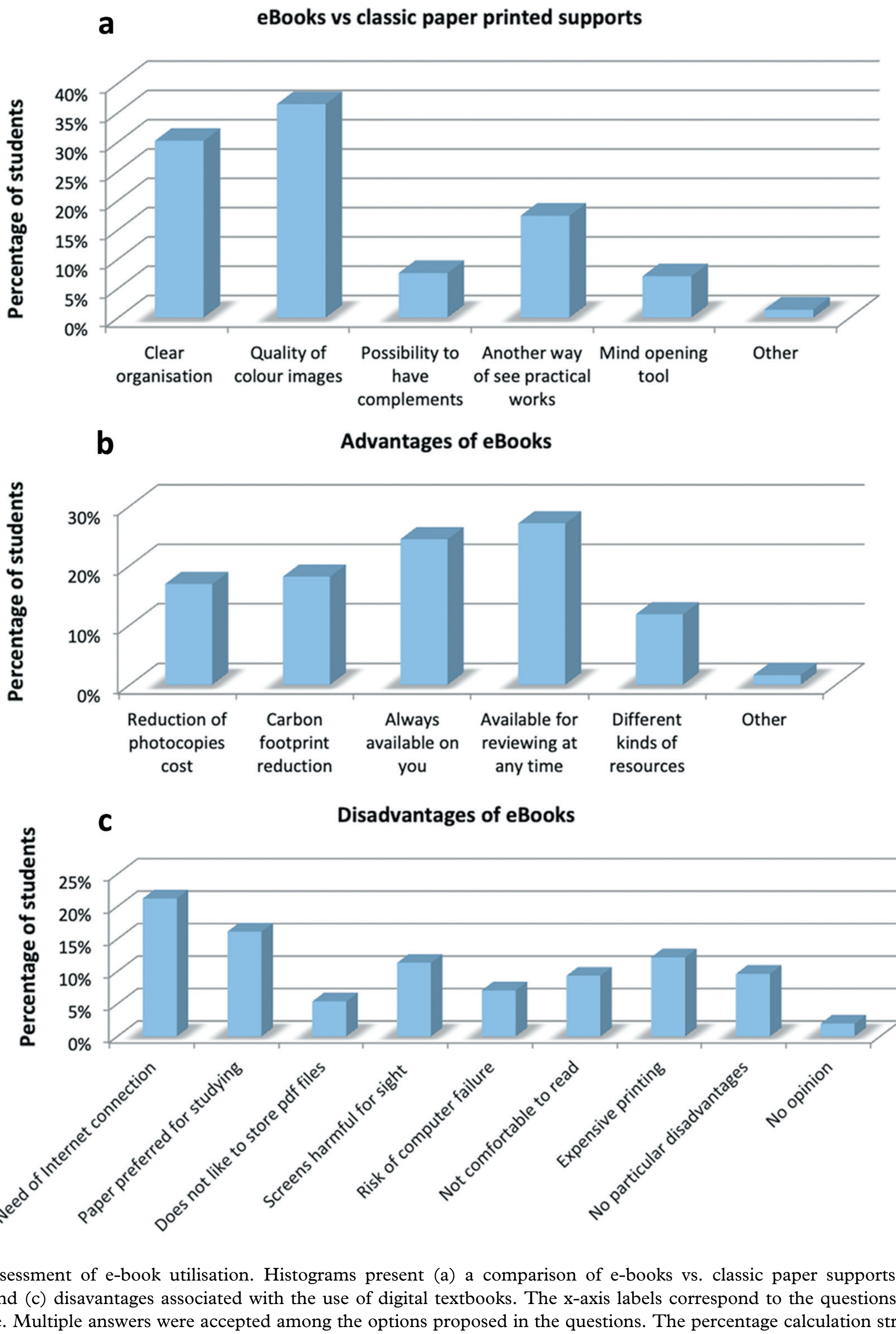

Figure 6. Assessment of e-book utilisation. Histograms present (a) a comparison of e-books vs. classic paper supports and the (b) advantages and (c) disadvantages associated with the use of digital textbooks. The x-axis labels correspond to the questions asked in the questionnaire. Multiple answers were accepted among the options proposed in the questions. The percentage calculation strategy for this kind of qualitative questions is described in the Materials and methods section.

cost in term of photocopying (16.9%) or the advantage to have them constantly available on digital devices for easy transport (24.4%), storage (18.4%) and reviewing (27.1%). However, students also pointed out some disadvantages linked to the use of digital textbooks (Figure 6(c)) in terms of the need for an Internet connection (21.2%) or the harmfulness of the screen light for sight (11.3%). These digital resources were considered uncomfortable to be read by 9.3% of students, and some were also afraid of a computer failure leading to the loss of the documents (7.1%). The introduction of these new supports was generally well accepted. Many students would like the same approach to be extended to the other disciplines of B.Sci1 (30.6%). Some undergraduates (11.8%) would reserve the use of digital textbooks for biology units and 51.2% of them would like these tools made available for all life sciences units associated with practical sessions (51.2%), such as physics or general and organic chemistry. Only a few students consider these digital resources useless for zoology learning (1.7%). Finally, 85.9% of questioned students asserted that these e-learning tools allowed them to work independently during their lab work on animal biology.

Discussion

Undergraduate students in life sciences arrive at university from high school with unfit learning methods. When commencing the bachelor's programme, they are exposed, in all disciplines, to new methods of teaching (inductive and by-heart learning) and to an impressive amount of quantitative learning (a high amount of scientific vocabulary to memorise). In addition, for the practical sessions they are supposed to rapidly associate practical skills with the basic knowledge contents of the units. Indeed, scientific units, and in particular animal biology, are frequently taught in the form of classic academic lectures in amphitheatre for a large number of students. As previously described in the USA (Freeman et al. 2014), this does not favour active learning of undergraduate sciences and induces passivity of students. Indeed, once theoretical courses are undertaken, students do not know how to use them in order to assimilate contents correctly and durably. This approach, mostly based on instructor-centred practice, should evolve towards student-centred active learning. The objective is to change instructors' methods to favour students' retention of disciplinary knowledge. Founded on these observations, we developed a novel approach for animal biology teaching that couples the classical academic lectures with hybrid distance- and face-to-face learning based on the utilisation of digital multimedia tools (Figure 7).

The pedagogical team analysed students' cognitive learning methods to establish the objectives of each practical session. One should keep in mind that neurocognitive development continues from adolescence into adulthood, as prefrontal cortex is remodelled. This continuous evolution could change learning abilities (Blakemore & Choudhuri 2006; Ng & Ong 2018). A digital learning environment is useful to motivate students and involve them in their own instruction. We note, therefore, that writing assessment success is also necessary to build knowledge networks. Thus, writing during lectures or during reviews allows better memorisation of vocabulary and better organisation/hierarchisation of knowledge. It will promote the later understanding of more complex concepts in a knowledge telling ≤ knowledge transforming process (Scardamalia & Bereiter 1987; Reynolds et al. 2012). To increase student performance, video-based instructions for dissection alone are not sufficient: cognitive overload could not be reduced to this activity (Raedts et al. 2017), as information should be provided through different channels (Mayer & Moreno 2003). Starting from these bases, and given the difficulties identified in the practical session and the feedback given during the evaluations of the animal biology unit, new e-learning strategies with clear objectives were designed. This work provides new insights into how undergraduates can work independently and how specifically targeted digital tools, made available on an educational platform, can help them. These aspects of accompanying students in learning and for their success, particularly in their first year of the bachelor's degree programme, are well supported by national or university institutions. Calls for projects are therefore regularly made and answered by some of our life sciences teaching teams (e.g. plant biology, biotechnology, chemistry, biochemistry). The animal biology team, in particular, received grants several times over several years from local (university grants for educational media resources production) and national (UNISCIEL) funding.

We produced a series of movies and e-books on zoology: these two supports were conceived to be complementary and to drive students throughout the active learning pathway before, during and after practical sessions. In the first phase of the project, teachers produced a series of HD videos showing animal anatomy and the dissection techniques to be applied during practical work sessions. These movies were conceived by zoology teachers

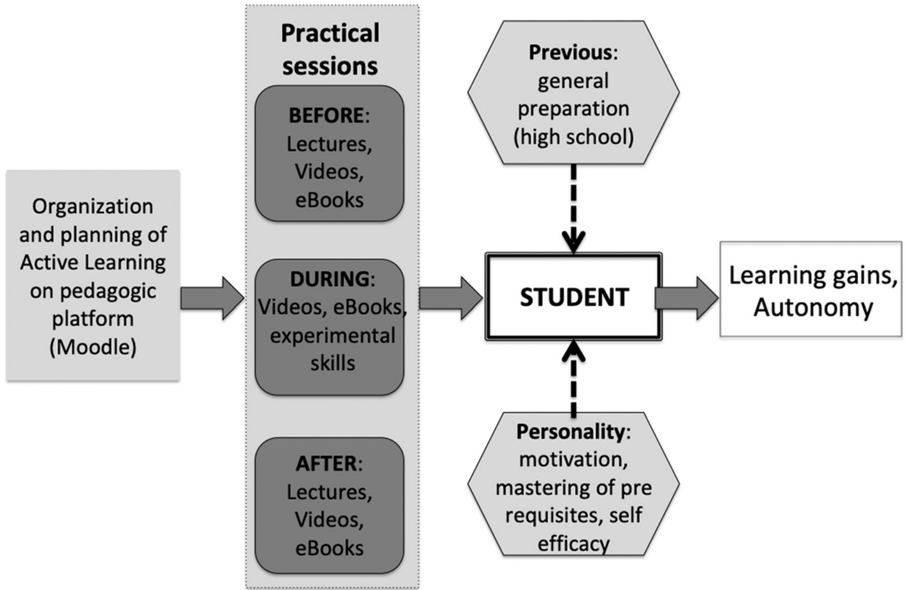

Figure 7. Student-centred pedagogical pathway proposed for animal biology teaching. In this scenario (horizontal arrows) the provision of digital tools stimulates undergraduates' active learning for studying and reviewing before, during and after practical sessions. Inputs consist of teachers' resources (lecture slideshows, videos, e-books/pdfs, complemented by websites, other YouTube videos, bibliography, etc.). To improve learning gains and autonomy, it is necessary to combine these resources with those of the students: previous school experience and their own personality (dotted arrows) (modified from Eddy et al. 2015).

together with the educational designer of the EdTech & Digital Pedagogy Department of the University of Lille. Using videos to illustrate the different topics in STEM units is a quite common method in active learning strategies. Multimedia instruction was tested to serve as an effective learning aid for chemistry students (Jordan et al. 2016). Videos were found to prepare students more effectively (resulting in +17% learning gains) and they were more independent during practical sessions. Other studies on usefulness and students' perception of videos were reported for molecular biology (Dupuis et al. 2013; Laneuville & Sikora 2015) and for physiology or anatomy teaching (Dobson 2009, 2010; Mayfield et al. 2013). A study was also performed to establish whether viewing narrated biology/animal physiology videos could statistically improve results on multiple choice questions (Stephens 2017). Students' unstructured comments in our questionnaire allowed us to establish that videos help them "to focus on main criterion of each group of animal" to be dissected compared with all data provided by traditional lectures. In addition, movies give "a more concrete and realistic idea of the organs in place, in the body of the animal, compared to the diagrams provided in the e-book or lectures". This is in accordance with a previous study by Stephens who reported that 50% of his students used such videos as stand-alone mini-lectures for reminding them of concepts soon after lectures (Stephens 2017). Stephens considers videos a valuable guide to help students to reproduce experimental techniques. This conclusion corresponds with the results obtained in our study, where students largely recognised the usefulness of our video productions for preparing the practical sessions: "we see what the organs look like, their colour and texture"; "very useful for a first approach to dissections"; "let see and review the gestures of dissection".

Students can view several times the videos available on the pedagogic platform, and reach in complete autonomy a good mastery of techniques, vocabulary and organ relationships. This reassures students and better prepares them for practical work and the final exam. Indeed, in the comments section of the questionnaire, undergraduates also mentioned the usefulness of these tools in reducing their stress during practical work sessions.

The increase in frequency of connections to the Moodle platform to view the movies exactly corresponds with the days immediately preceding the practical work and the days right before final examinations. This confirms that students regularly watched these videos to prepare the practical sessions and review for evaluations. Interestingly, the trend in daily numbers of views measured for our students in animal biology is similar to that observed for molecular biology students (Laneuville & Sikora 2015), suggesting that this kind of learning activity is not discipline-dependent. In addition, this trend confirms that undergraduates completely integrated the use of these tools into their studying habits, validating our objective to make these tools useful, indeed indispensable, for students' active learning.

This active learning strategy was completed by the production of a series of digital textbooks linked to the movies described above. In this case the objective was to complete, using written text and interactive pictures, the video description of animal dissection. In addition, the software used for the production of these interactive textbooks (iBooks Author by Apple) facilitates the integration of several complementary tools (glossary, photo galleries, interactive images, hypertext or quizzes) aimed to push students to widen their knowledge on the different topics. The use of this free software constitutes a major advantage in term of format, interactivity and editing quality. Unfortunately, the whole panel of functions of the system can only be exploited using Apple devices, owned by only 27% of our students and generally too expensive for them. PC or Android users can only consult the textbook exported in pdf format. Although the pdf version of this support remains extremely useful and appreciated by the students for aesthetics and the abundance and quality of content, it involves the loss of many interactive options such as a glossary, quizzes or photo galleries, reducing the possible pedagogic applications of these tools. Generally, however, the availability of e-books/pdf on different devices (smartphones, tablets or computer) is an important element facilitating students' consultation in any situation or environment. Thanks to the large availability of Internet connections for the present generation (91.2% for the tested sample) the possibility to consult these digital tools while moving remains a major point. Tablets were reported to be relevant devices for learning human anatomy (Cochrane et al. 2013; Scibora & Mead 2018) and other university curricula (Nguyen et al. 2015); nevertheless, mean exam scores did not differ between tablet and no-tablet course groups (George et al. 2013). The effects of this device on learning gains remain inconclusive (Nguyen et al. 2015), and George et al. (2013) noticed a decrease over time of tablet utilisation. Moreover, academics and students also indicated that such devices and related apps are rapidly outdated (Rossing et al. 2012).

Once a dissection is completed, students generally make observation drawings or schematic representations of different organs and systems with the corresponding keys. We consider this mixed scenario very important for learning, including the observation of a panel of digital images together with the assessments of a "classic" hand-made drawing created during the practical session. This approach reinforces observation capabilities and is in accordance with the conclusions of Basey and collaborators, which consider drawing an experimental skill useful for students learning biology to acquire, especially in anatomy (Basey et al. 2015).

Concerning the learning method, independently from the appreciation of digital tools in terms of quality and usefulness, many students prefer studying on paper supports. They generally print out the e-books ("I need to have written notes"; "I rewrite protocols, schemas are redone before the practical session and to revise"), although this solution involves additional costs. Many of them make their own notes or summary sheets merging the information from academic lectures and the digital textbooks. This approach permits students to avoid tablet or computer transport, makes these documents available in any situation and preserves them from loss in the case of computer bugs. Although in general students appreciate the interactivity of mobile technology (Rossing et al. 2012), as our own students noticed, it cannot replace printed handouts (George et al. 2013). Beside videos, textbooks (iBooks/pdf) were provided on the pedagogic platform with the objective to improve student autonomy during the session. Mayfield and collaborators noticed that with the use of videos their students were less likely to seek an instructor during the practical sessions in human anatomy (2% compared to 32% if no video on dissection was available; Mayfield et al. 2013). These authors concluded that digital manuals improve student engagement, help to achieve objectives and enhance efficiency of dissection education. Globally, from the introduction of these new e-learning tools, we also observed a better mastery of techniques and autonomy during practical sessions.

The effectiveness of the animal biology e-learning tools described here spurred some teachers at our institution to develop similar strategies for plant biology learning. This evolution of the project is consistent with students' requests to extend the use of digital textbook to other biology fields. The first trials of e-book utilisation in plant biology received very positive feedback from colleagues and students, encouraging the teaching team to further develop the use of such tools.

The University of Lille possess an ancient naturalist collection with a significant historical value. A programme of 3D photo digitalisation of this scientific heritage has been under development for two years (http://photo3d.univ-lille1.fr/360/) in the Biology Department, with the aim to preserve and valorise this scientific collection and to use it for animal and plant biology teaching. The integration of scientific heritage in a pedagogic scenario in science units was recently reported by Cook et al. (2014). These authors estimate that the use of natural history collections could help students to explore biodiversity and, in general, improve STEM undergraduate students' education by changing their attitude from passive to active exploration of these data. We have recently made available for our bachelor's students several hundred 3D photos of animal and plant specimens from our collections, enriched with keys and animations. These permit students to virtually handle, on different devices (computer, tablet, smartphone), rare, ancient or fragile samples with high scientific and historical value. The association of 3D photos with the other digital tools described here brings new potential for distance and face-to-face learning about animal and plant biology. In this sense, a project of producing a series of files "at a glance" on mammal teeth and diets to be used during practical work in the B.Sci2 programme is currently underway. To reinforce this interest in local scientific heritage, a minor teaching unit on museology is now proposed as part of B.Sci2 to students in the organisms and population biology curriculum.

Conclusions

As a whole, the digital supports presented here constitute new, effective tools for zoology teaching. The measurable practical goals (dissection rating) indicate significant progress in techniques and handling of dissection tools. Both students and teachers recognise the usefulness of movies for technical learning, with consequent progress in practical work quality during semester sessions and final exams. In contrast, the objective of improving the theoretical learning through the production and use of digital supports was not completely achieved. Learning feedback on animal anatomy slightly increased with the introduction of these new tools. Also, after several readings or viewings of digital supports, students have trouble retaining the large amount of vocabulary associated with the body plan and frequently mix up or forget the names of the organs within the animal. They also have difficulty comparing the anatomy of species belonging to the same group (e.g. squid vs. mussel), demonstrating only partial comprehension of the general bauplan of the phylum. This weakness in consolidating new knowledge is generally applicable to other STEM disciplines as well. It can be explained by the large amount of information undergraduates have to absorb in a short time, all teaching activities (academic lectures and practical classes) being concentrated in a 12–14-week period/semester for all the different units. In addition, this overload of work is associated with the new education methods students encounter in the first year of the bachelor's programme. Indeed, a clear improvement in zoology learning feedback has been observed in second-year students who use similar digital tools.

In conclusion, the use of new e-learning resources for zoology teaching globally improved students' knowledge, experimental skills and autonomy. Their use and effectiveness are dependent on the constant personal work to be furnished by students. In addition, these distance-learning tools cannot substitute for the face-to-face inductive teaching of academic lectures or the practical experimental sessions that remain indispensable components for learning in biology in particular and in STEM disciplines in general.

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