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DOI
10.1016/j.ijmedinf.2023.105269

Publication date
2023

Document Version
Final published version

Published in
International Journal of Medical Informatics

International Journal of Medical Informatics 180 (2023) 105269

Contents lists available at ScienceDirect

International Journal of Medical Informatics

journal homepage: www.elsevier.com/locate/ijmedinf

EASIER: A new model for online learning of minimally invasive surgery skills

Ignacio Oropesa [a,*], Luisa F. Sánchez-Peralta [b], Carmen Guzmán García [a], Magdalena K. Chmarra [c], Krisztina Berner-Juhos [d], Calin Tiu [e], Christos Mettouris [f], George A. Papadopoulos [f], Andreas Papadopoulos [g], José Blas Pagador [b], Joeri Post [h], Jenny Dankelman [c], Ana González-Segura [i], Francisco M. Sánchez-Margallo [b,j], Enrique J. Gómez [a,k], The EASIER Task Force

[a] Biomedical Engineering and Telemedicine Centre (GBT), ETSI Telecomunicación, Center for Biomedical Technology, Universidad Politécnica de Madrid (UPM), Avda Complutense, 30 28040, Madrid, Spain
[b] Jesús Usón Minimally Invasive Surgery Centre, Carretera Nacional 521, Km 41.8 10071, Cáceres, Spain
[c] Department of Biomechanical Engineering, Faculty of Mechanical, Maritime and Materials Engineering (3mE), Delft University of Technology, Mekelweg 2 2628 CD, Delft, the Netherlands
[d] Semmelweis University, Faculty of Medicine, HVC, Department of Surgical Research and Techniques, Nagyvaead sqr. 4, Budapest, Hungary H1089
[e] MEDIS Foundation, 83 Grivitei, Campina 105600, Romania
[f] University of Cyprus, Department of Computer Science, CY-2109, Nicosia, Cyprus
[g] Cyprus Research and Innovation Center Ltd, 28th Octovriou Ave. 72, Office 301, Engomi 2414, Nicosia, Cyprus
[h] SIMENDO BV, Vijverhofstraat 106 3032 SP, Rotterdam, the Netherlands
[i] NTT Data, Avda. Cortes Valencianas 39,9C 46015, Valencia, Spain
[j] Centro de Investigación Biomédica En Red de Enfermedades Cardiovasculares CIBERCV, Av. Monforte de Lemos, 3-5 28029, Madrid, Spain
[k] Networking Research Center on Bioengineering, Biomaterials and Nanomedicine (CIBER-BBN), C/ Melchor Fernández Almagro, 3 28029, Madrid, Spain

ARTICLE INFO

Keywords:
Education
Distance
Medical Education
Computer simulation
Training Simulation
Surgery
Information and Communication Technologies
Projects

ABSTRACT

Introduction: Technology Enhanced Learning (TEL) can provide the tools to safely master minimally invasive surgery (MIS) skills in patient-free environments and receive immediate objective feedback without the constant presence of an instructor. However, TEL-based systems tend to work isolated from one another, focus on different skills, and fail to provide contents without a sound pedagogical background.
Objective: The objective of this descriptive study is to present in detail EASIER, an innovative TEL platform for surgical and interventional training, as well as the results of its validation.
Methods: EASIER provides a Learning Management System (LMS) for institutions and content creators that can connect and integrate TEL "external assets" (virtual reality simulators, augmented box trainers, augmented videos, etc.) addressing different skills. The platform integrates all skills under an Assessment Module that measures skills' progress in different courses. Finally, it provides content creators with a pedagogical model to scaffold contents while retaining flexibility to approach course design with different training philosophies in mind. Three courses were developed and hosted in the platform to validate it with end-users in terms of usability, performance, learning results in the courses and student self-perception on learning.
Results: In total 111 volunteers completed the validation. The study was limited due to the COVID-19 pandemic, which limited access to external assets (virtual reality simulators). Nevertheless, usability was rated with 73.1 in the System Usability Scale. Most positive aspects on performance were easiness to access the platform, easiness to change the configuration and not requiring additional plug-ins to use the platform. The platform was rated above average in the six scales of the User Experience Questionnaire. Overall, student results improved significantly across the three courses ($p < 0.05$).

Abbreviations: AA, Associated Action; AS, Associated Skill; KA, Knee Arthroscopy; LC, Laparoscopic Cholecystectomy, LMS: Learning Management System; LP, Lumbar Puncture; LRS, Learning Record System; MIS, Minimally Invasive Surgery; SUS, System Usability Scale; TEL, Technology Enhanced Learning; UEQ, User Experience Questionnaire; VR, Virtual Reality.

* Corresponding author.
E-mail address: i.oropesa@upm.es (I. Oropesa).

https://doi.org/10.1016/j.ijmedinf.2023.105269
Received 2 June 2023; Received in revised form 6 October 2023; Accepted 21 October 2023
Available online 24 October 2023
1386-5056/

Conclusions: This study provides, within its limitations, evidence on the usefulness of the EASIER platform for distance learning of MIS skills. Results show the potential impact of the platform and are an encouraging boost for the future, especially in the aftermath of the COVID-19 pandemic.

1. Introduction

Technology enhanced learning (TEL) in minimally invasive surgery (MIS) has become established over the past decades. Box trainers or virtual reality (VR) simulators are widely used to train technical skills in patient-free environments [1,2]. E-learning portals provide remote access to video libraries to learn cognitive and procedural skills. Training in nontechnical skills, such as decision-making or teamwork, can be achieved thanks to virtual immersive environments [3]. Reported advantages of using TEL are: (1) reproducibility and/or adaptability of tasks and scenarios for different students in patient-free environments; (2) monitoring of physical or qualitative parameters; (3) subsequent potential for immediate feedback and objective assessment without the presence of an instructor; and (4) ubiquitous or universal access to online resources [4].

The increasing use of TEL in MIS training makes necessary to assert its role within existing training curricula. The availability of TEL resources in hospitals and training centers has on occasions been subject to economic or operational reasons rather than to pedagogical ones [5]. Moreover, TEL-based learning and assessment is done on a system-to-system basis. Each tool provides its own pass/fail criteria and cannot be easily cross-referenced with other training systems (addressing different or even the same skills) to provide an integrated assessment of skills. Without standards, establishing benchmarks between professionals trained in different institutions, regions or countries becomes a challenge [4].

TEL enables distance learning, which can provide ubiquitous, self-paced and adapted learning opportunities to trainees, and it has been shown that it can improve, or at least match, traditional learning programs in surgery and anatomy training [6]. Surgical e-learning portals in particular offer universal access to collections of annotated and/or didactic contents and videos unrestricted by time, place, costs and/or need of training personnel. However, Maertens et al. [7] revealed several limitations that these portals have in common. Firstly, the learning scope of the didactic contents, mostly limited to cognitive skills, “should ideally be complemented with other activities such as simulation-based training to develop the entire spectrum of surgical competency”. Secondly, contents are delivered without a sound pedagogical background. The Technology Enhanced Surgical Training Report of the Commission on the Future of Surgery refers to “a perceived lack of cross-pollination between education theory and surgical training” to inform the effectiveness of TEL adoption in surgery [4]. Seldom are e-learning contents informed by learning theories and pedagogical models [8], which ultimately may lead to trainees’ demotivation and drop-out from the course.

In 2018, the European Commission gave green light to the EASIER Project (588404-EPP-1–2017-1-ES-EPPKA2-KA), which strived to tackle the challenges listed above. The project proposes an innovative platform providing a Moodle-based Learning Management System (LMS) that can connect and integrate TEL “external assets” (VR simulators, augmented box trainers, augmented videos, etc.). In practice, this means that online courses can be built making use of the authoring tools provided by the LMS per se, as well as seamlessly integrating tasks and/or contents from third-party systems. To support course creators in this endeavor, guidelines for instructional design of courses, based on a pedagogical model [9], are also available and are an integral part in the platform design. Finally, the platform collects user performance on the different skills and assets and integrates them under a complete assessment profile accessible both to residents and mentors. The goal of this study is to present in detail the EASIER platform and its pedagogical guidelines, as well as the main conclusions of its validation including content, usability, performance, user satisfaction and perception, and pedagogical value aspects.

2. Materials and methods

This is a descriptive study involving the development of an online teaching platform for minimally invasive surgery and interventional techniques. Validation of the EASIER platform in terms of content, usability, performance, user satisfaction and perception, and pedagogical value was carried out at project’s end.

2.1. Pedagogical foundations

To address the lack of pedagogical standards we integrated the MISTELA pedagogical model [9] to deliver content creators with a tool to design sound pedagogical contents based on the affordances available to them. A brief description is included here for the sake of comprehension; for further details, the reader is referred to [9].

The model provides a guide to scaffold contents allowing content creators to retain flexibility with respect to their preferred learning theories and pedagogical approaches. Scaffolding is achieved in two ways: (1) defining a closed set of general skills to be acquired, including technical, cognitive, decision making, stress management, interpersonal, and leadership skills; and (2) proposing a common structure for didactic contents, by which activities are centered around a specific surgical procedure and structured according to anatomy, equipment and instruments, indications and contraindications, procedural steps, and complications.

Flexibility is attained by adopting Conole’s 3D pedagogy framework [10], which provides a systematic mapping of tools and resources to expected learning outcomes and pedagogical theories of preference. Mapping is described in terms of the Activity Theory [11], transforming higher-level activities into outcomes by means of actions. The model provides recommendations on: (1) how to map potential actions to available tools and resources; (2) select the best matching actions according to the preferred pedagogical approach; and (3) develop a pedagogical profile for the resulting activity driven from the appropriateness of each tool or resource. The profile is represented over the so-called 3D framework across three different axes:

- Individual – Social: learning is considered a mainly individual experience or achieved through interaction with others.
- Non reflection – Reflection: learning comes through drill and practice, or from conscious elaboration about experience.
- Experience – Information: learning depends on direct experience, or on using available sources of information.

One activity may be performed using different actions, depending on the situation, resources available, and so forth. A training activity is thus composed of actions that are carried out by means of different tools. Tools are, therefore, multi-purpose and cannot be directly affiliated to a particular pedagogical approach, but rather to the kind of actions they facilitate. Thus, mapping a tool can serve as a broad reference, but only makes sense when the tool is paired with an action that has a clear pedagogical profile. This reveals the importance of building a TEL environment starting with the kind of actions it is supposed to enable, because the tools included in it will only make sense if they have been designed according to *how well* they match the pedagogical profile of those actions.

2.2. The EASIER platform

The EASIER platform was designed and developed by a multidisciplinary team of engineers, clinical personnel, and pedagogical advisors following a knowledge elicitation process of interviews and surveys reported in [12]. Fig. 1 depicts the platform's architecture, which will be discussed in the following subsections. The platform distinguishes between different user roles:

- Administrator: user in charge of technical support, performance, and security of the platform.
- Content creator: user with editing capabilities but no student monitoring/assessment permissions.
- Teacher: user with both editing and student monitoring/assessment permissions.
- Student: user who benefits from the learning and training provided by courses.
- Institutions: entity that provides an institutional umbrella to users (e.g., hospitals or training centers).

2.2.1. EASIER LMS

The LMS is the front-end of the platform, handling user interactions, as well as all interactions with external assets and internal components. It is based on the open-source Moodle LMS [13], using a course-layout to host the different activities. Changes to the interface and layout options were made to the default configuration to disable unnecessary options and provide a cohesive look.

2.2.2. External assets

The platform enables interaction with external assets to enhance students' learning and allow them to acquire further skills. xAPI e-learning specification was selected as the main standard for content packaging and delivery between platform and external assets, due to its flexibility to integrate data outside of the scope of an LMS, or track data from simulators and serious games [14]. External assets are linked in such a way that, within an activity, actions using them may be integrated seamlessly and adapted to the activities' learning outcomes and assessment. Currently available assets include VR-simulator SIMENDO [15], motion/force analysis systems for box trainers ForceSense [16] and EVA [17], augmented video authoring tool and player AMELIE [18], arthroscopy simulator Passport [19] and an epidural needle insertion box trainer [20].

2.2.3. Learning record store (LRS)

The LRS is the database responsible for storing and retrieving xAPI statements for learning tracking from both internal sources and external assets. It is based on the open-source solution Learning Locker [21]. It can be structured into organizations, stores and clients. Organizations (i.e., *Institutions*) contain one or more stores and clients. In EASIER, a separate client is assigned to each external asset that will save its data to a store. In this way, each external asset can only access data within its store.

To enable user activity tracking (i.e.: login, student enrolment to a course, quiz attempts) in Moodle through the LRS, the Logstore plugin is used [22]. Additionally, a Statement Retrieval interface is included, responsible for retrieving learning analytics' content stored in the LRS from the different modules.

2.2.4. Launch server

To enable seamless integration and interaction of external assets with the LMS, the platform deploys a Launch Server that uses the xAPI-Launch algorithm [23]. The Launch Server is used by the external assets as a medium for their communication with the LRS. The main concept of launching content in xAPI refers to the mechanisms that enable a learning provider (the LMS in our case) to provide its users with access to external content, such as simulators. Fig. 1, (right) shows the sequence diagram of the interactions between the different components. When the users access the content, it is the content itself that is responsible of using xAPI and logging the user activities to the LRS. Students are redirected, through the LMS, to the selected external asset. Once they are finished using it, as well as during their interaction with it, the asset will communicate with the Launch Server and send the results and activities in the form of xAPI statements. To avoid security issues, the Launch Server enables the use of temporary access tokens to ensure that the asset does not receive direct access to the LRS, and enforces restrictions on the xAPI integrations. When the user communicates with the external asset, through an LMS-provided URL, they can use their own

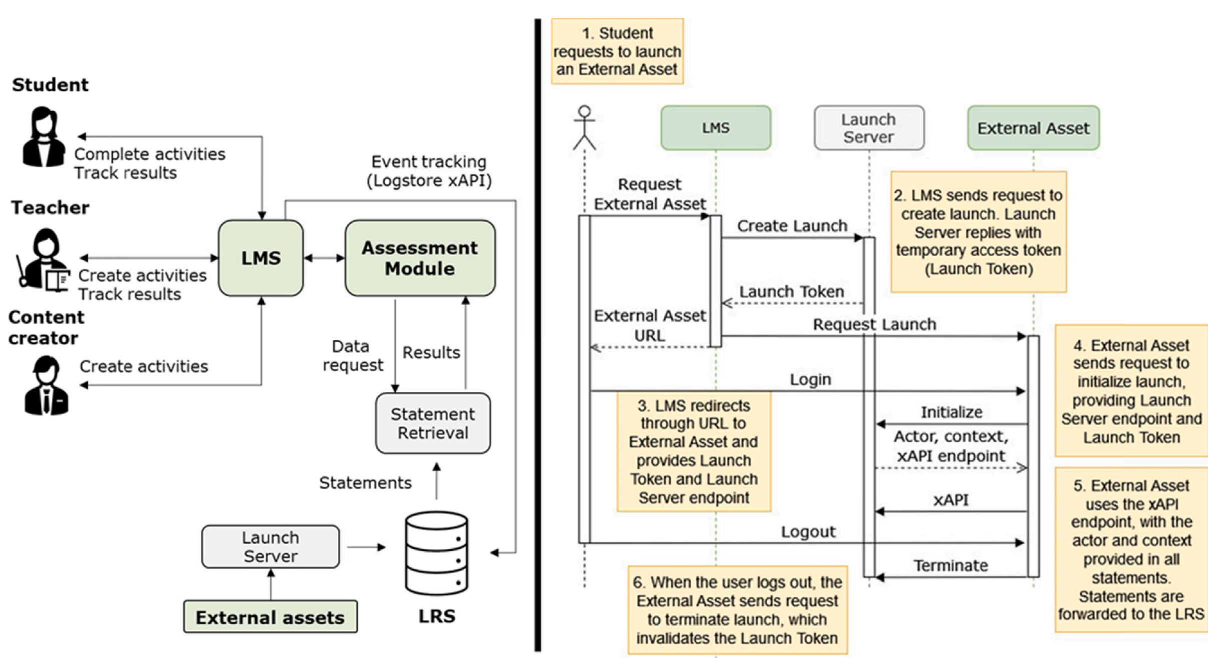

Fig. 1. Left - Architecture of the EASIER platform. Right – Sequence diagram describing the interaction between the user, LMS and external assets via the Launch Server.

authorization credentials to login to the external asset. The Launch Token is used to map the LMS user account with the external asset user account, without exchanging any account information.

2.2.5. Assessment module

Finally, the platform implements an Assessment Module to track progress per skill. The module is skills-oriented and aligned with the pedagogical model. As such, *Teachers/Content Creators* can define learning outcomes for an activity, assign them to one or more skills (see "Section 2.1″) and set them weights based on their importance (Associated Skill, AS). Likewise, every action must necessarily be related with one or more learning outcomes of the course, by assigning a relative weight to each learning outcome covered by the action (Associated Action, AA). Finally, for each action creators must provide an Expected Workload (EW) relative to the total workload of the activity.

Skill progression is modelled in three levels following a bottom-up approach. At the action level, the module defines the maximum skill trained per action ($\%_{SkA}$), obtained for each skill involved in each action as:

$$\%_{SkA} = 100^* \sum_{i=1}^{N} AS_i {}^* AA_i \quad (1)$$

Where N is the number of the action's learning outcomes associated with the skill.

At the activity level, maximum skill progress per activity ($\%_{Skill}$) is obtained by aggregating $\%_{SkA}$ for all actions covering that skill weighted by the expected workload for each task.

$$\%_{Skill} = 100^* \sum_{j=1}^{M} \%_{SkA} {}^* EW_j \quad (2)$$

Where M is the number of actions associated with the skill.

At the platform level, the total percentage of maximum skill progression ($\%_{SkT}$) is obtained by taking the average of $\%_{Skill}$ for all user-enrolled activities. A schematic representation of the model is provided in Fig. 2.

Finally, the model considers a monthly 2 % drop in skill progress to account for skill retention, to encourage students to refresh their skills by redoing actions or carrying out new ones. This percentage was determined because a 24 % of yearly decrease without evidence of skill improvement is appropriate for encouraging continuous learning [24].

2.3. Case studies

Three case studies were created by expert panels from the Jesús Usón Minimally Invasive Surgery Centre (Spain), Department of Surgical Research and Training, Semmelweis University (Hungary) and MEDIS Foundation (Romania): (1) laparoscopic cholecystectomy (LC), considered the gold standard for the surgical removal of the gallbladder; (2) knee arthroscopy (KA), a common orthopedic procedure to manage knee disorders; (3) lumbar puncture (LP), performed to withdraw cerebrospinal fluid or to inject anesthetic drugs.

Fig. 3 shows the 3D mapping for the most common actions implemented in the three courses. The actions reflect the intended orientation of the content creators. These lean towards a reflective/informative pedagogical approach to nontechnical skills learning (square and diamond markers) and hands-on/experiential for technical skills (circular markers). Courses are mostly focused on individual learning, but the inclusion of specific discussion boards enables mechanisms for collaborative learning (hexagonal markers).

The three courses were implemented into the platform in English, Spanish, Romanian, Dutch and Hungarian. Tasks featuring augmented videos were implemented with AMELIE, whilst tasks requiring the use of a simulator were implemented using the SIMENDO VR simulator. Video 1 (provided as supplementary material) shows the implementation of the LC case study in the EASIER platform.

2.4. Validation

Validation was designed based on the e-MIS framework [25], which evaluates three dimensions of Web environments for training in MIS: content, usability, and functionality performance. Two additional

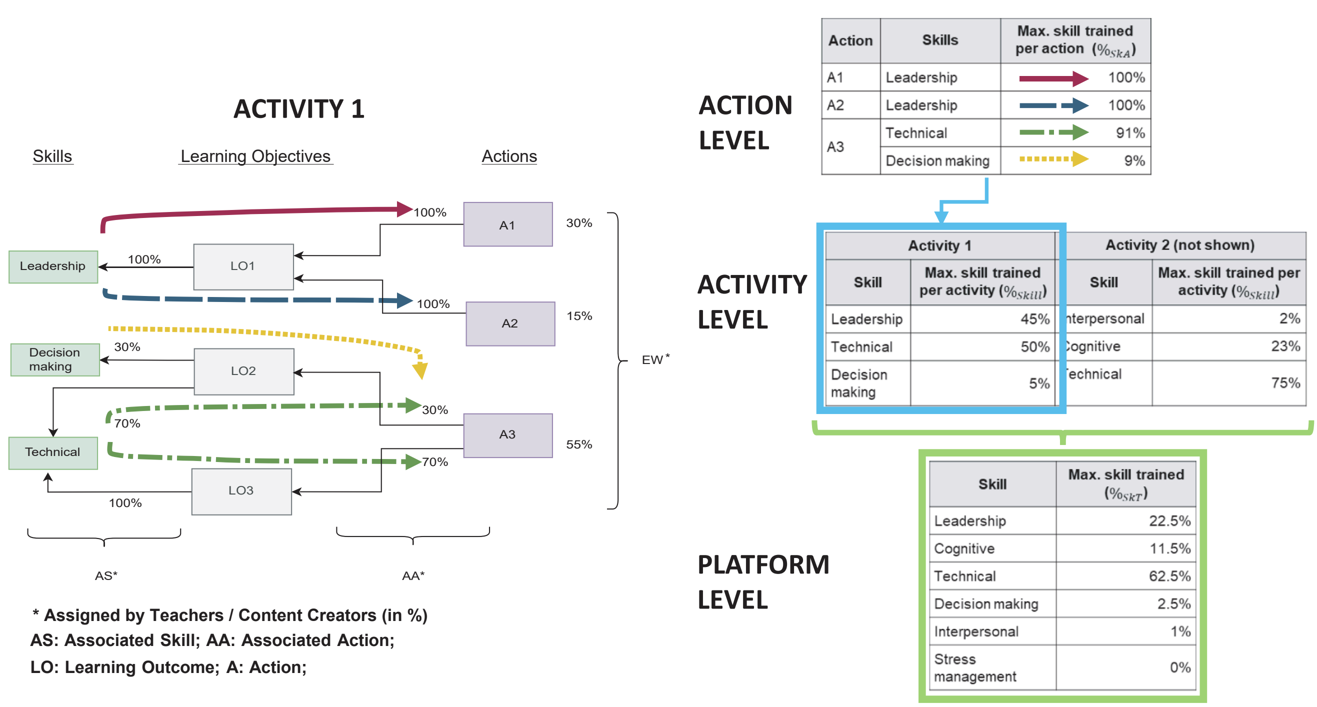

Fig. 2. Example of the Assessment Module's functionality for a student enrolled in two activities/courses. Left side: skill progression example for Activity #1. Coloured paths are shown to indicate the calculation of $\%_{SkA}$. Right side: summary of skill progression for the student in the platform (including Activity #2). LO: Learning Outcome; A: Action; AS: Associated Skill; AA: Associated Action.

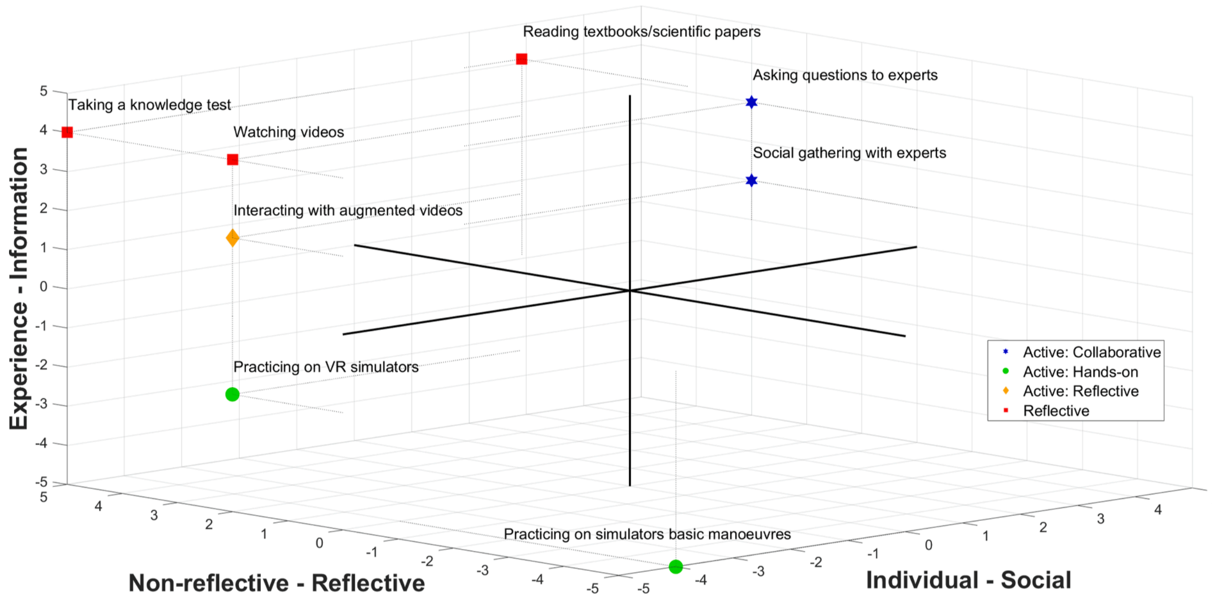

Fig. 3. 3D mapping of courses' actions according to the pedagogical model. Markers reflect the intended pedagogical approach, or how learning is realized through the actions.

aspects were included: user satisfaction and perception, and pedagogical model validation. The latter was validated through: (1) an analysis of learning results in the different courses; and (2) student self-perception on learning.

Content validation was presented as part of a previous work [26]. Experts on surgical training were satisfied with the structure and the quality of the courses and found them well prepared according to the best practice of each technique.

Usability, performance, and pedagogical model validation were planned as part of a pilot study both with residents and expert surgeons. This pilot was organized as a supervised, hybrid trial, as theoretical contents were available online but access to external assets required attendance to onsite sessions. The pilot was scheduled to begin in March 2020, but due to the COVID-19 outbreak, access to end users was compromised due to the strict sanitary protocols and the increasing clinical duties of end users. To minimize exposure and reduce the interaction between end users, research staff, and shared simulators, initially planned trials had to be first delayed and, finally, modified into a mostly online validation.

An open call for participants was announced through the media channels of the participating institutions (mailing lists, LinkedIn and Twitter). An introductory webinar was carried out via Zoom on the 17th of December 2020. After the webinar, consenting participants were enrolled to the EASIER platform. The trial period ran from December 21, 2020 until April 7, 2021. During this time, participants had free access to the platform to complete one or more courses.

Upon completion of the course(s), participants were requested to complete an online questionnaire. The first part of the questionnaire addressed demographic questions.

The second part addressed usability, performance and user satisfaction. Usability was assessed by means of the System Usability Scale (SUS) [27]. Performance aspects were assessed by means of a Likert-based ad-hoc questionnaire with 10 questions. User's satisfaction and perception was based on statements matching the six-dimensions' model created by Sun et al. [28], adapted where necessary to the EASIER platform. The User Experience Questionnaire (UEQ) was also used [29]. The items of the UEQ consist of 7-points scales with a pair of terms with opposite meaning at each end. The items are related to six scales: attractiveness, efficiency, perspicuity, dependability, stimulation, and novelty. The UEQ benchmark [30] provides ranges for each of the six scales and helps evaluating new products where a previous assessment does not exist.

The last part of the questionnaire addressed self-perception on learning, as part of the pedagogical model validation. Implemented questions were inspired by Thalheimer's Performance-Focused Learning Surveys [31]. Questions were designed to provide specific answer options based on learner understanding, motivation, and after-learning opportunities to put the acquired knowledge into practice.

To evaluate learning results, pre-post questionnaires addressing comparable skills were developed for each course (available for reference as supplementary material). Participants had one attempt at each test. Completion of the pre-test was compulsory to gain access to the course contents. Once completed, participants were given free access to the course, to carry them out at their own pace (within the timeframe of the validation). Post tests were completed at the end of each course.

Shapiro-Wilk tests were run on pre-post data to determine normality. In cases where the null hypothesis could be rejected ($p > 0.05$), paired t-tests were applied to determine whether there were significant differences between pre and post scores. Otherwise, Wilcoxon's ranked test was employed. Differences were sought for each individual course and for the average score for all courses ($p < 0.05$). To ensure the scores obtained in the post-test were relevant, participants who only completed the pre-test and post-test without going through the course contents were not included in the analysis. Completion rate (C) was calculated for each course considering as enrolled those students who completed at least the pre-test, while completing the course required content visualization, as well as completing both pre- and post-tests.

$$C = \frac{(N^{o}\ of\ people\ completing\ the\ course)}{(N^{o}\ of\ people\ completing\ the\ pre-test)} \quad (3)$$

3. Results and discussion

3.1. Participants' demographics

In all, 143 participants were registered on the EASIER platform. In total they completed 132 courses. From these participants, 111 final questionnaires were obtained. Since not all respondents completed every section, for the following subsections the total number of answers received per question will be declared. In terms of demographic data, 110 participants answered the provided questions. Gender was balanced between participants: 58 women (52.7 %) - vs 52 men (47.3 %) and the predominant age range was 23 to 30 years old (N = 86, 78.2 %) in comparison to 30 to 45 years old (N = 19, 17.3 %) and 45 to 60 years old (N = 5, 4.5 %), which matches the prevalence of 1st to 3rd year residents (N = 88, 80.0 %) over 4th and 5th year residents (N = 7, 6.4 %), fellow surgeons (N = 4, 3.6 %) and attending surgeons (N = 11, 10.0 %). These percentages were considered representative of the target audience: mostly young students and residents in training, but also appealing to veteran professionals looking to learn new techniques. As for specialty, gynaecology (N = 33, 30.0 %) stands out over general (N = 26, 23.7 %), orthopaedic (N = 20, 18.2 %) and urologic surgery (N = 10, 9.1 %). Remaining 19.1 % (N = 21) corresponds to other specialties. Participants were from Hungary (N = 93, 84.5 %), Romania (N = 10, 9.1 %), Spain (N = 6, 5.5 %) and Portugal (N = 1, 0.9 %). 41 participants (37.3 %) had no previous experience with e-learning courses, 47 (42.7 %) had taken one or two, 12 (10.9 %) had taken between 3 and 5, and 10 (9.1 %) had taken more than 5. The fact that more than 50 % of participants had previous e-learning experience was considered a positive factor, as it implied that they were familiarised with TEL and thus were less susceptible to a Pygmalion effect bias if their expectations were set lower and had grounds for comparison. Lastly, participants rated their computer skills mainly as intermediate (N = 83, 74.5 %), with few experts (N = 22, 20.0 %) and novices (N = 7, 5.5 %). Ideally, having so many participants with computer literacy should reduce the bias that a lack of these skills may cause on the learning process [32].

Given the constraints imposed by the COVID-19 pandemic, only 9 students in Romania had access to the simulators to train technical skills, and even so under strict protocols and limitations.

3.2. Usability and performance validation

Results on usability are shown in Fig. 4a. Mean value for SUS was 73.1 [N = 110, Quartile 1 = 65.0, Quartile 3 = 84.4; Interquartile Range = 19.4]. Since values over 68 are considered acceptable [33], the platform was considered usable by participants. Differences on usability perception between participants with different computer skills or number of e-learning courses were investigated, but none of them showed statistically significant differences according to the U-Mann Whitney test (p-values: 0.367 and 0.703, respectively).

Results on users' opinion on performance are shown in Fig. 4b (N = 106). Users considered that it is easy to access the platform and to

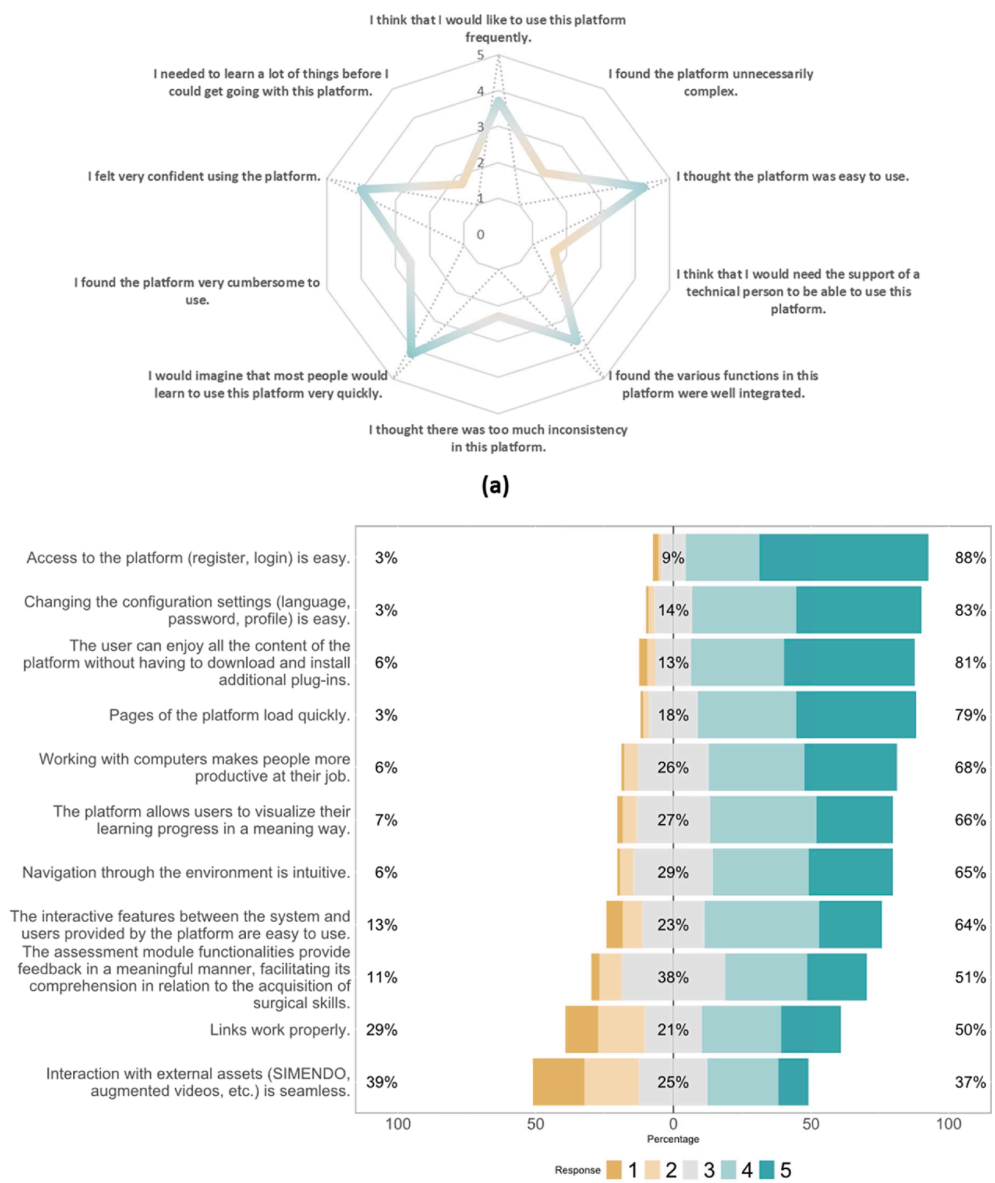

Fig. 4. Usability and performance validation: (a) SUS scores plot. Dotted lines indicate the best possible outcome for each question; (b) performance results. 1: Completely disagree – 5: Completely agree. Percentages reflect total negative (left column), neutral (middle column) and positive (right column) answers.

change the configuration. Similarly, the fact that there is no need to use additional plug-ins to use the platform was well rated. In contrast, there were two statements rated under 3.5 points. On one hand, the interaction with external assets was not seamless for the users. This rating might be biased due to the impossibility for most of them to have access to the simulators, and only to the AMELIE augmented videos. On the other hand, there were negative scores related to links not working properly. This might be due to external reasons, as some videos were hosted on YouTube, or related with isolated issues, which would also lead to the larger variability in the responses.

3.3. User satisfaction and perception validation

Results on users' opinion on satisfaction and perception are shown in Fig. 5a (N = 106). All responders filled out all 19 questions on the questionnaire, resulting on an average positive answer with > 3.0 points for the 15 questions with a positive direction and around 2.0 points for the remaining 4 questions with negative direction. According to the users' opinion, working with computers makes people more productive (4.0 ± 0.9), and they are not uncomfortable with their use (1.9 ± 1.1). Similarly, participants confirmed that taking courses online allowed them to spend more time on other non-related activities (3.5 ± 1.1). This is also supported by the fact that many responders answered that there were no difficulties for taking courses online (2.4 ± 1.2) and were able to fulfil them in parallel with their work effectively (3.8 ± 1.1). Participants also felt that the quality of the course was largely unaffected by conducting it online (3.2 ± 1.2). Most of the users think that EASIER allowed for a seamless experience without technical problems (3.7 ± 1.0). In general, using TEL would enhance and improve effectiveness in surgical skill (3.6 ± 1.0), and overall, they found TEL is useful in surgical training (3.7 ± 1.0). Most became skilful with the platform (3.7 ± 1.0) and found easy learning to operate the TEL system (3.9 ± 0.9).

Results from the UEQ (N = 100, Fig. 5b) show that the platform is above average in all scales (i.e., 25 % of results in the benchmark are better while 50 % of results are worse). The "stimulation" scale is rated within the limits to be considered as good, (i.e., 10 % results in the benchmark are better and 75 % of results are worse), with a score of 1.389 (Confidence interval = 1.17–1.61). On the other hand, "novelty"

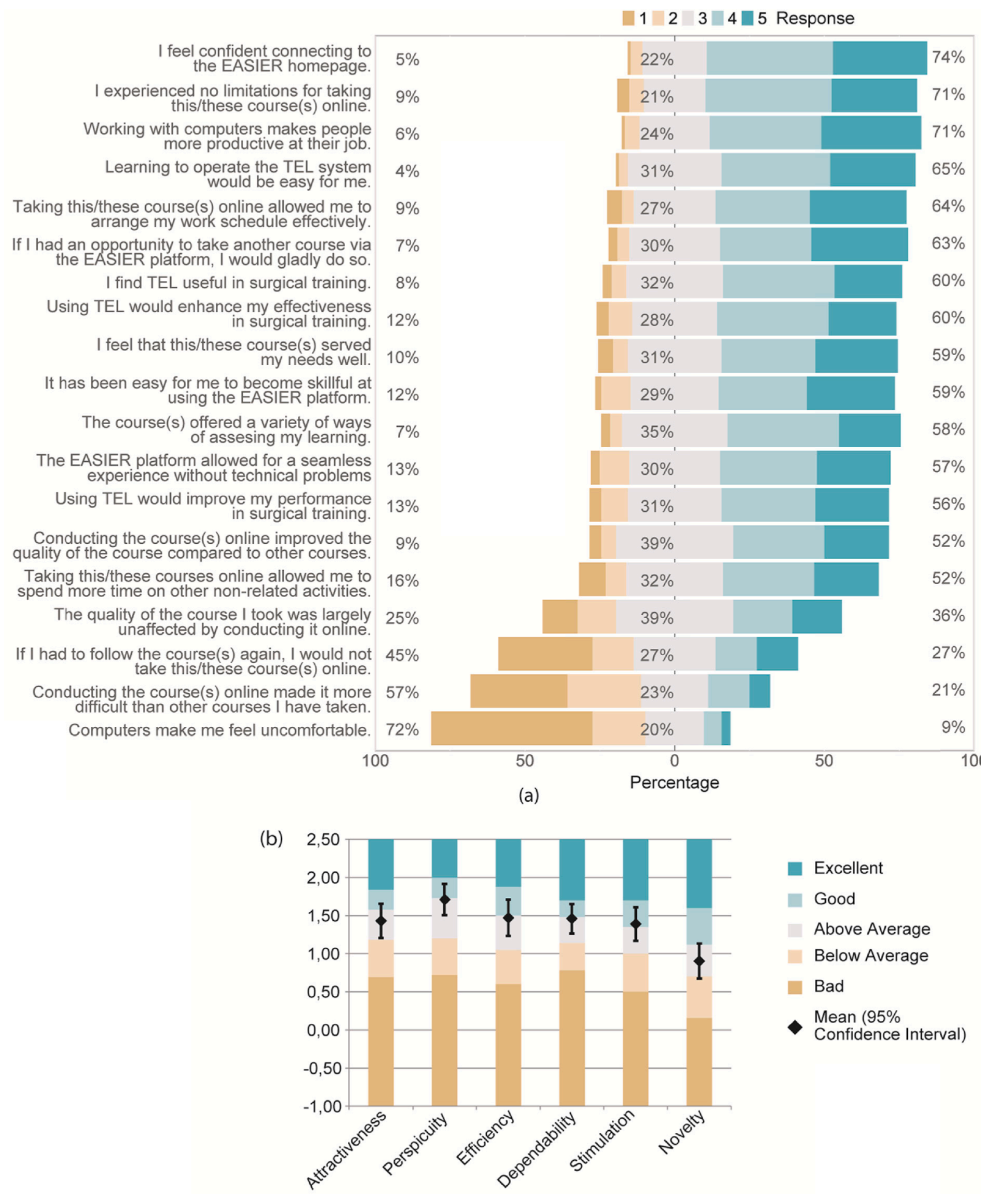

Fig. 5. User satisfaction and perception validation: (a) user satisfaction results. 1: Completely disagree – 5: Completely agree. Percentages reflect total negative (left column), neutral (middle column) and positive (right column) answers; (b) UEQ results.

is the lowest scored scale, with 0.90 (Confidence interval = 0.67–1.13), which might be due to the fact that the platform is based on Moodle, which is well known by the respondents, and that novelty lies on specific aspects (pedagogical model and external assets connection), which, without access to simulators, had less impact in user experience.

3.4. Pedagogical model validation

In total, participants completed 132 courses. To avoid bias in the results, the few subjects who received simulator training were excluded from the pre-post test analysis. Likewise, since the effects of training were being measured, fellow and attending surgeons were excluded too. In total, 112 courses were considered in the statistical analysis.

Table 1 shows the mean and standard deviation scores for pre and post-tests. Scores followed a normal distribution for all cases except LP. In average, differences between tests were significant across the three courses and for each individual course. These results indicate that course completion effectively improves the acquired knowledge of the procedure taught.

Results on student self-perception on learning can be found in Fig. 6. In average, the learning experience obtained a rating of 3.7 ± 1.0 in a 5-point Likert scale, being 5 the highest score (Fig. 6a).

The average likelihood in which participants would use what they learnt in the next 3 months was 63.0 %, while the likelihood to share what they had learnt was 56.7 % (Fig. 6b). When asked about the motivation to complete future courses in the platform, only 5/89 (5.6 %) of participants answered they would not be interested at all to do so (Fig. 6c).

64/89 participants claimed to have a solid (or better) understanding (71.9 %) of the concepts taught after completing the courses (Fig. 6d). However, 71/90 (79 %) felt they needed more experience (Fig. 6e).

The aspect of learning that helped students the most within the platform were AMELIE embedded videos. Aspects that could be improved mainly involved further interaction with the simulators. Both aspects point to the direction that the incorporation of assets could indeed be a valuable tool for surgical training. In fact, participants involved in on-site simulation tasks suggested to include further surgical examples to the courses. This should encourage content creators to incorporate tasks pertaining other external assets into future courses and reinforces the premises behind the ideation of EASIER.

3.5. Study contributions

To our knowledge, EASIER is the first platform for MIS online training to potentially address all the necessary skills required to become a proficient surgeon. Existing training platforms have mostly focused on training and tracking cognitive skills. Some have focused on developing educational material from video repositories. Examples include WebOP [34], C-SATS [35], or WebSurg [36]. Others provide complete e-learning content aimed at self-paced learning. GIBLIB [37], for example, curates high quality medical educational videos allowing for VR visualization and interactions. In addition to training cognitive skills, some platforms allow training technical skills. Osso VR [38] offers surgical VR simulations, which provide information on instruments, complications, and steps of different procedures. Surgical Safety Technologies [39] provides a modular platform for training technical and nontechnical skills (i.e., teamwork or stress management). It supports mixed reality simulations and provides objective assessment of proficiency using academically validated frameworks. None of these platforms disclose the use of pedagogical models to structure the learning experience. Furthermore, none of them offer third-party external asset integration, and thus contents are restricted to the specified formats, tools and resources provided by their developers. EASIER does not impose any kind of learning asset, but rather provides flexibility through the combination of three key enabling factors: (1) a pedagogical model to accommodate different learning styles and plan any activity regardless of the means to implement them; (2) an Assessment Module where content creators can configure the relative contribution of each action to the skills' progress of the trainee, and (3) an open API to integrate third-party assets to facilitate the learning process. This study has provided valuable insights into the usefulness of EASIER: both in terms of user acceptance and perceived usefulness of the platform itself, and on the value of the hosted contents following the proposed pedagogical designs.

Table 1
Learning results.

Course	Completed	C	Pre-test	Post-test	p-value
LC	65	0.89	7.4 ± 1.2	8.5 ± 0.9	<0.001*
KA	28	0.966	7.2 ± 1.7	8.7 ± 1.4	<0.001*
LP	19	0.905	8.9 ± 0.6	9.7 ± 0.5	<0.001*
Average	112	0.911	7.6 ± 1.4	8.8 ± 1.1	<0.001*

Pre/post-test results given as (mean + std). *Indicates statistical significance.

3.6. Study limitations

There were some limitations concerning the validation of the platform. As already mentioned, limited access to the simulators meant that most participants were not able to complete simulator-dependent tasks and thus could not complete the whole activities. Moreover, those who did were excluded from the analysis of the learning experience to reduce bias. Additionally, by opening the validation to the surgical community, we prioritised platform exposure, but lost control on the number and percentage of courses completed remotely. This introduced an inherent bias in the learning intervention, and as such on the learning results. Course completion was also prioritised against other features, such as in-depth review of the Assessment Module.

The intended pedagogical approach to the three courses was almost identical. Thus, validation of the pedagogical model was limited to the configurations implemented as a design choice by the course creators. For example, participants focused more on individual learning and thus less time was devoted to the social dimension. While more a design feature of the courses rather than limitation, in hindsight encouragement of collaborative engagement could have boosted the social dimension of learning. Due to course design choices, only two external assets were featured in the contents. Additional courses featuring other external assets may help further boost the interest in the platform. Finally, the time constraints of the validation trials prevented the analysis of aspects related with retention and spacing effect.

4. Conclusions

This study describes a novel technological platform for online training of MIS and interventional techniques. It has provided, within its limitations, evidence on its usefulness, functionality, and pedagogical value. Nevertheless, further studies, including a broader range of courses (with different pedagogical perspectives) and external assets, should be carried out to ratify our findings.

In the aftermath of the COVID-19 pandemic, the relevance and impact of distance learning has become evident in many application fields, as a facilitator of flexible and ubiquitous learning opportunities. The surgical and medical field need to embrace this opportunity to explore new avenues of delivering training beyond the constrictions of onsite learning and/or traditional e-learning experiences. EASIER addresses several of the most pressing needs of surgical e-learning platforms, integrating a pedagogical scaffold for content creators and opening its spectrum beyond that of cognitive skills through the integration of both open and proprietary third-party external assets. The flexible approach of both the pedagogical model and the Launch Server means that the platform can be easily applicable to other medical disciplines and even other fields of knowledge. Based on our real-world evaluation, we believe on the need for solutions such as EASIER, able

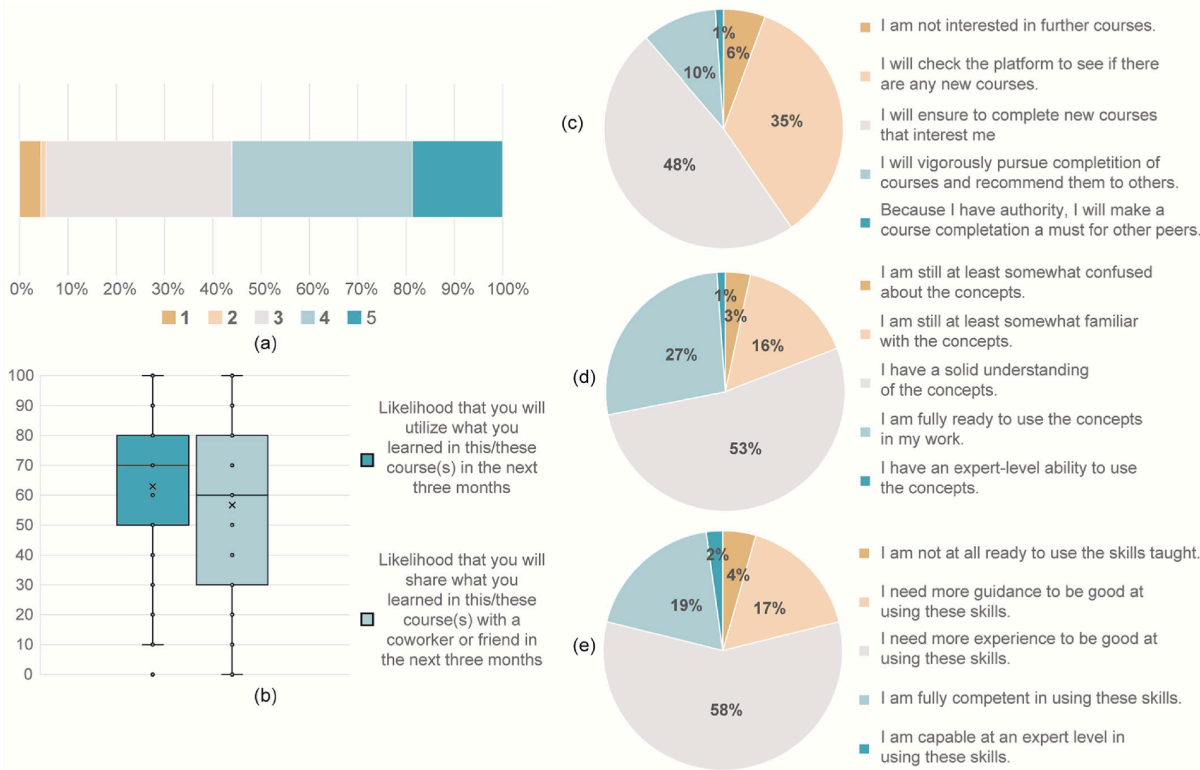

Fig. 6. Pedagogical model validation: (a) overall learning experience (N = 91), rated from 1 = "very little value" to 5 = "highest value"; (b) likelihood of applying (N = 88) and sharing (N = 87) what has been learnt, expressed as %; (c) adherence to the platform (N = 89); (d) learning self-perception (N = 89); (e) self-confidence in cognitive skills learnt (N = 90);

to provide a centralized, online hub for learning and training multiple skills. Thanks to our solution allowing the connection of different external assets, we are convinced that EASIER has the potential to cater to different training centres with different training philosophies across Europe.

5. Summary points

- Problem: Current Technology Enhanced Learning (TEL) systems for surgical training do not offer a pedagogically sound, holistic learning experience.
- What is already known: TEL has proven its usefulness as a complement for patient-free, ubiquitous learning and training. However, technologies are implemented in isolation with respect to each other, addressing different skills and failing to provide trainees with an integrated and pedagogically grounded learning experience.
- What this paper adds: An innovative, validated approach to surgical education to connect and integrate different TEL assets and skills.
- Additionally, the EASIER platform concept can easily be exported to other domains of medical and nonmedical knowledge.

CRediT authorship contribution statement

Ignacio Oropesa: Conceptualization, Methodology, Writing – original draft, Visualization, Funding acquisition. **Luisa F. Sánchez-Peralta:** Methodology, Data curation, Validation, Formal analysis, Resources, Writing – original draft, Visualization. **Carmen Guzmán García:** Methodology, Software, Validation, Formal analysis, Writing – original draft. **Magdalena K. Chmarra:** Methodology, Validation, Writing – review & editing. **Krisztina Berner-Juhos:** Resources, Validation, Writing – review & editing. **Calin Tiu:** Resources, Validation, Writing – review & editing. **Christos Mettouris:** Software, Writing – review & editing. **George A. Papadopoulos:** Software, Writing – review & editing. **Andreas Papadopoulos:** Software, Writing – review & editing. **José Blas Pagador:** Validation, Resources, Writing – original draft. **Joeri Post:** Software, Writing – review & editing. **Ana González-Segura:** Project administration, Funding acquisition, Writing – review & editing. **Francisco M.Sánchez-Margallo:** Validation, Project administration, Funding acquisition, Writing – review & editing. **Enrique J. Gómez:** Project administration, Funding acquisition, Writing – review & editing.

Declaration of Competing Interest

Project EASIER (588404-EPP-1–2017-1-ES-EPPKA2-KA) is funded with support from the European Commission. The European Commission's support for the production of this publication does not constitute an endorsement of the contents, which reflect the views only of the authors, and the Commission cannot be held responsible for any use which may be made of the information contained therein.

Acknowledgments

The EASIER Task Force is comprised by David Gutiérrez, Juan Francisco Ortega-Morán, Evangelia Vanezi, Alexandros Yeratziotis, Loizos Koukoumas, Andrea Ferencz, George Alexandru Negoita-Tiu, Vlad Eugen Tiu, Sakyi O.B. Amoa, Willem Nerkens, Tim Horeman and Patricia Sánchez-González.

Appendix A. Supplementary material

Supplementary data to this article can be found online at https://doi.org/10.1016/j.ijmedinf.2023.105269.

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