Enabling Surgeons to Create Simulation-Based Teaching Modules

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Abstract

To broaden the use of simulation for teaching, in particular of new procedures and of low-volume procedures, we propose an environment and workflow that lets surgeon-educators create the teaching modules. Our challenge is to make the simulation tools accessible, modifiable and sharable by users with moderate computer and VR experience. Our contribution is a workflow that promotes consistency between instructional material and measured criteria and makes the authoring process efficient, both for the surgeon, and for computer scientists supporting the simulation environment.

1 Introduction

The increasing deployment of commercial simulators in surgical education attests to the general perception that virtual training is a valuable experience over conventional dry-lab training. The rationale for training surgeons with the help of 3D virtual scenarios is particularly strong for minimally invasive surgical techniques (see e.g. [Gallagher et al. 2005; Gurusamy et al. 2009]). By allowing trainees to practice decision making and laparoscopic execution prior to entering the operating room, such simulators can make costly trainee time in the OR more valuable, increase the safety to patients and reduce the need for in vivo animal practice. And with the compression of surgical training due to work-hour rules uncoupling of instruction from place and time is ever more important.

While commercial surgical trainers are becoming widespread and find their way into the curriculum, they provide a limited set of training modules. The cost structure favors the most common and the most basic surgical procedures. The corresponding teaching modules are programmed by engineers and modifications will always depend on development cycles and time to market. This means that in particular *new procedures and low-volume procedures* currently do not benefit from the trend towards simulation for training. Moreover, fixed-function simulations can not convey the individual variations in technique that surgeon-educators consider an important component of the master-apprentice relationship in traditional surgical education.

Our long-term goal therefore not just to generate new teaching modules, but to craft a software framework within which surgeons themselves define and adjust (author) interactive simulation teaching modules. The expectation is that, just as with desktop publishing, removing intermediaries will speed transmission of individual expertise and quickly document novel surgical techniques and variants by example. That is, we aim to broaden the access to simulation for teaching and to help scientific discourse with the help of simulation: to quickly document, teach and assess knowledge of variants and innovations in technique, including extreme scenarios.

Challenge. It is amply documented that developing and combining the necessary state-of-the-art graphics, numerical and interface techniques underlying interactive 3D virtual scenario is highly non-trivial. Fortunately, computational simulation techniques in the biomedical, computer and mechanical engineering have made great strides (see e.g. [Cheng et al. 2008; Zhou et al. 2009; Deo and De 2009; Allard et al. 2009; Taylor et al. 2010]) and increased GPU processing power, accessed via shaders, CUDA or OpenCL, reduces even complex algorithms to a real-time experience.

But, our longterm goal is even more ambitious: we hope to make the simulation tools accessible, modifiable and sharable by users with moderate computer and VR experience. A key issue is therefore the work flow for the surgeon-educator when creating a teaching module. In this paper, we present an approach for *making such an authoring process more efficient* – both for the surgeon-educator acting as author or as instructor and for the computer scientists supporting the simulation. Leveraging advanced but standard web and database technology as well as an existing simulation platform, a key feature of our approach is to let the surgeon-educator determine the content while at the same time promoting consistency between instructional material and measured criteria.

2 Tools and Methods

Approach. We are developing an open-source framework to enable surgeons-educators to apply simulation within their laparoscopy curriculum. Specifically, we leverage the TIPS (Toolkit for Illustration of Procedures in Surgery) infrastructure [Kim et al. 2007] for the 3D virtual scenario.

To present a simple work flow to the surgeon-educator creating a teaching module, a web-based central form Fig. 5 guides the surgeon in decomposing the procedure into steps with their tasks (what to do and how) and errors (what not to do and how to identify mistakes) as is typical in traditional teaching. From this decomposition, our software generates pre-filled templates of web-pages for instruction and for outcomes, a list of surgical tools and 3D anatomy (organs, vessels) and properties thereof (including haptic and reporting properties); see **Built-in assessment** below. The point in generating templates is two-fold: to *simplify authoring* and to *promote consistency* between stated and measured trainee performance criteria.

To focus the teaching modules on *measurable outcomes determined by the surgeon-educator*, trainee performance is assessed by comparing to a min-max-range set by the instructor's execution of the teaching module (see **Built-in assessment** below).

Tools. As shown in Fig. 1, the physical setup of the teaching modules includes two monitors showing respectively the 3D virtual scenario on the local PC and the web-based instructions on any web-browser. Two Phantom Omni devices provide six degrees of freedom movement measurement and three degrees of force-feedback. Including a PC with a high-end graphics card, the total cost is ca $5,000.

For the *3D virtual scenario*, we leverage the TIPS simulation environment which allows the surgeon-author to create, place and size 3D anatomy (organs, vessels, etc.) occluding fatty tissue [Punak et al. 2008], covering peritoneum [Myles et al. 2009], select tools and to interactively adjust properties, such as the haptic feedback force.

For the *web-based component*, we leverage open-source dynamic web-application software (Ruby on Rails, MySQL) and technologies (JWPlayer, Scriptaculous, AJAX) that will work on almost any browser platform to provide text, audio, video and picture (multi-media) support, allow gathering input data and auto-generating templates as well as reports to users. The web-tools also enable our distributed team to collaborate efficiently as privileged users can access it from anywhere using any modern web-browser. Finally, the web-based interface makes it easy to publish resulting teaching modules as downloadable file-bundles.

Methods. The key to streamlining the workflow for both developer and author is a web-based central form Fig. 5. It is the basis for auto-generating drafts for instruction pages, evaluation forms and questionnaires; serves as a todo-list for the author; and it conveys essential details about the surgical procedure to technicians (who may pre-assemble the 3D virtual scenario) and alert developers to missing objects or features in the database, such as a new surgical tool. Fig. 4 summarizes the basic structure: teaching modules are built around the steps of the procedure. Drafts of questionnaires are generated from a transcription of the atomic tasks and errors and added as instruction pages for revision by the author. Also an outline of evaluation form is created to be filled with upper and lower bounds data by the surgeon-educator's performance in the simulation environment.

Author View. For the surgeon, creating a teaching module amounts to (cf. Fig. 2)

(i) filling in the central form:
— *deconstructing* the procedure into its main steps and
— *deciding* on what surgical tasks to teach and test in each step,
— *uploading* instructional multimedia illustrations such as a video clip of the real surgical procedure for each step,
— *uploading or creating* the virtual scenario (organs, vessels, tissue and surgical tools in the 3D scene), and
— *customizing* it (modifying color, scaling elasticity, enable feedback, enable reporting, etc.),
(ii) *performing* the tasks of each step,
(iii) *attaching* to the teaching modules web pages: video, text book illustrations, sketches and/or audio as available and appropriate.
The author customizes complex behavior, such as haptic feedback of the fatty tissue, by choosing among a parameter-range determined to be acceptable by the model-builder. If the parameter-range is insufficient, the author picks a model with a different range of behavior.

The essence of the teaching modules are tasks and safety instructions (errors). Every **task** (what to do and how) must be measurable within the 3D virtual scenario. For example, the task 'incision of the peritoneum' should be made specific by stating 'for the full craniocaudal extent of the gland, from the diaphragmatic level to the renal vein' and this is made measurable by having the surgeon-educator perform the task inside the 3D virtual scenario (**built-in assessment** below describes how this is ultimately converted into measurements for comparison). Every **error** (what not to do and how to notice mistakes) has to be reported by the 3D virtual scenario output and hence this reporting function has to be enabled by the author (see **reporting** below). Finally, the author may choose to add **comments** that give immediate feedback (e.g. bleeding when the force exceeds a threshold) or context (video of surgery) but that do not themselves influence assessment or outcome.

Deconstructing and specifying the tasks and errors via the central form is the instructor's main effort when creating a teaching module. The software layer generates from the central form
– templates for the instructions;
– templates for pre-questions and post-questions
– a list of object reporting values and
– the catalogue of feedback items (Fig. 3).
These templates not only help the author with the deconstruction and are convenient but promote *consistency of tasks and measurements* in the teaching module.

The object **reporting** values are properties that the author enables in the 3D virtual scenario for inclusion into the assessment data stream. For example, in the step: incision of the peritoneum, the data collected internally for the feedback form are sequences of (u, v) parameters of the underlying surface representation (see **Built-in assessment** below for their use). Similarly, cautery too close the vena cava, can be reported. Internally, the distance sampler between vena cava and the cautery tool is enabled which outputs into the feedback stream when the distance is too low.

Trainee View. A trainee can view the instruction pages via a standard web-interface which guides the trainee through a pre-questionnaire, the surgical procedure overview, tasks and safety information assorted in steps, an illustration of each step from video and a video of the simulated procedure, a post-questionnaire and the evaluation form (see Fig. 4). After each illustration of a step, the trainee is asked to replicate it within the 3D virtual scenario. At the end of a training session, the results are compared to the instructor's.

Support Staff and Developer View. If the surgeon-author has local support staff, they can use the central-form's steps and tasks to pre-assemble the scenario for the 3D virtual scenario, by downloading and arranging the anatomy and setting initial properties. Often, no help is needed for an author, already when the whole scenario can be downloaded, e.g. when a variant of an existing procedure is to be illustrated.

Similarly, developers can be alerted to missing objects (for example the multi-stapler in the appendectomy module) or object functionality. Object a The surgery video clip attached to the central form and the function description in the task and error specification help to give context and allows for a distributed, asynchronous, collaborative work flow. (We prefer to work this way since instructional material and delivered functionality are in sinc when a formal interface is used.)

Built-in assessment via performance ranges. The teaching modules are built around surgeon-set assessment criteria expressed as tasks and errors. The final detailed feedback compares trainee performance relative to the *instructor-established* performance range of these criteria. (The original surgeon-educator acting as author and the instructor need not be the same person). Acceptable ranges of measured criteria do not have to entered explicitly, say as Newton/cm^2. An author instantiates (by downloading from our web-site TIPS-central.info or creating ab initio) and then customizes the anatomy in the 3D virtual scenario to match appearance and feel (for haptic resistance when probing organs, vessel and tissue) and *enables the reporting of relevant measurements*. (The modes of output are part of the C++ definition of the organ or tool created by a developer.) For example, once enabled (by right-click selection or by copied default), the kidney (data structure) reports how often it has been probed during a task and with what force; or whether cautery was used (excessively) in its close proximity to the vena cava and for what length of time; or the peritoneum reports the length and approximate placement of an incision. Once all report values are enabled, an author, or an instructor who wants to change the author's range, runs through each task two or more times establishing maximal and minimal acceptable values for enabled values (forces, lengths and orientation of cuts, time limits or correct choice of surgical tools). That is, rather than having to specify absolute values, the instructor will run through the teaching module generating low and high comparison values. For example, the instructor incises the peritoneum for the least allowable length in one run and for the maximal length in a second run. (The length of an incision, possibly several cuts, is compared as the max diameter of the tree of individual cuts measured in the domain of the surface.) Once enabled, an error such as penetrating the liver with a Maryland dissector during an adrenalectomy or excessive cautery is reported in the final feedback (Fig. 3, Fig. 4 *right*). Trainee interaction with the teaching module's 3D virtual scenario then generates all the raw data used for the assessment of the performance of the trainee on the teaching module. (Separate questionnaires assess the perceived quality of the teaching module.) The resulting stream of measurements from the 3D virtual scenario is simply compared to the min-max-range performance on the same teaching moduleusing a generic PHP-based parser. The feedback, on the web-interface, states whether the incision was sufficient or else the percentage by which it was too short or too long. That is, the final feedback form lists deviation from range rather than absolute numbers.

Altogether, this yields a simple, adaptable feedback mechanism that focuses teaching modules on the outcome. For example, the focus can be on safety by prominently marking trainee errors such as laceration or puncturing of the aorta or the intestines and closely monitoring the use of cautery.

3 Results

To date, teaching modules of variants of three laparoscopic procedures have been created: removal of the adrenal gland, the appendix and the spleen. Each module combines web-based instructions using text, audio, video both of the surgical procedure and the TIPS simulation, and feedback based on the trainee questionnaires and on the performance in the adjustable 3D virtual scenario. Every teaching module is structured according to the holistic view recommended e.g. in [Gallagher et al. 2005]: (cf. Fig. 4 for the numbering) after prior (1) teaching of relevant knowledge i.e., anatomy, pathology, physiology; (2) instruction on the steps and task of the procedure: 'what to do and how'; (3) defining and illustrating common errors 'what not to do and how to identify mistakes'; (4) pre- and post test of (1-3) to later gauge knowledge improvement; (5) technical skills training on the simulator; (6) (blood, color change) provide immediate (proximate) feedback when an error occurs; (7) summative at the completion of a trial. Iterating a teaching module allows to chart progress, varying a teaching module allows implementing teaching techniques such as shaping (progressively increasing the difficulty), fading (removing clues), or backward chaining (increasing the number of tasks starting from the back).

Only the arenalectomy module has to date undergone peer review by 6 surgeons and initial assessment with 8 residents at two research hospitals. Formal testing, in a uniform environment with a sufficiently large pool of trainees is scheduled for 2011. In any case, this measurement of final *impact of a teaching module* is not the focus of the present paper. Rather, we focus on how well our approach supports surgeon-educators in *creating teaching modules*. To this end, we measured authoring a new laparoscopic appendectomy module.

The authoring of the **appendectomy module** (see Fig. 2) was squeezed into an active surgeon's time plan in two sessions over a two week period. This was the author's first module. While we were physically present during the authoring (we had to deliver the Omni feedback devices), in order to have a sustainable setup for asynchronous, distributed development, we successfully left the description of the authoring tasks to a short instruction video on our web-site and to the prompts of the central-form.

The appendectomy teaching module was then created from scratch requiring 3 hours of the author's time over two sessions. Fig. 2 gives a detailed time-line. The 2 hours of support time were not caused by explaining the authoring interface but needed to create a newly requested multi-stapler and corresponding organ-functionality in the database.

4 Discussion

Creating simulations in 3D virtual scenario is challenging and a source of hard, computational problems for the community for sometime to come. By making the central-form rather than the 3D virtual scenario the cornerstone of our development, we make a conscious decision to let the individual surgeon-educator drive the use of simulation in the hope that this broadens the use of simulation and points us to features that promote learning – even at the cost of the highest-fidelity experience. This is a point of view shared by some experts [Gallagher et al. 2005; AAMC 2007]. That is, we assume that realism of the 3D virtual scenario of the teaching modules is important only in so as it influences quality of teaching. In particular, the 3D virtual scenario has to satisfy the surgeon-author's expectations not the bio-engineer's. A surgeon-author may well choose to color arteries a solid red and veins a solid blue in violation of accurate physical modeling of a wet-lab scenario; or to artificially overemphasize the stiffness of a vessel or brittleness of an organ to highlight possible complications; or the author may suppress detail.

Empowering each surgeon-author to teach their approach could potentially reduce quality and consistency *vs* commercial modules. For example, it is possible that an author or instructor sets performance ranges too tight (although we have not observed specialist surgeons making this mistake), leave out a task or a safety issue deemed obvious. As with standard publication, peer review rather than the authoring environment has to take care of quality issues. The teaching modules can be disseminated and shared via the internet. The long-term hope then is that criteria will be vetted by the surgical community and evolve into standards.

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Figure 1: **teaching modulesetup.** The surgeon-author runs through the teaching module, setting the acceptable performance ranges. The monitor on the left, in the background, displays the web-based instructions, questionnaires, video, and the final feedback statistics. The other monitor, here a laptop, displays the 3D virtual scenario (run on the laptop). The interface consists of two Omni devices (robotic arms).

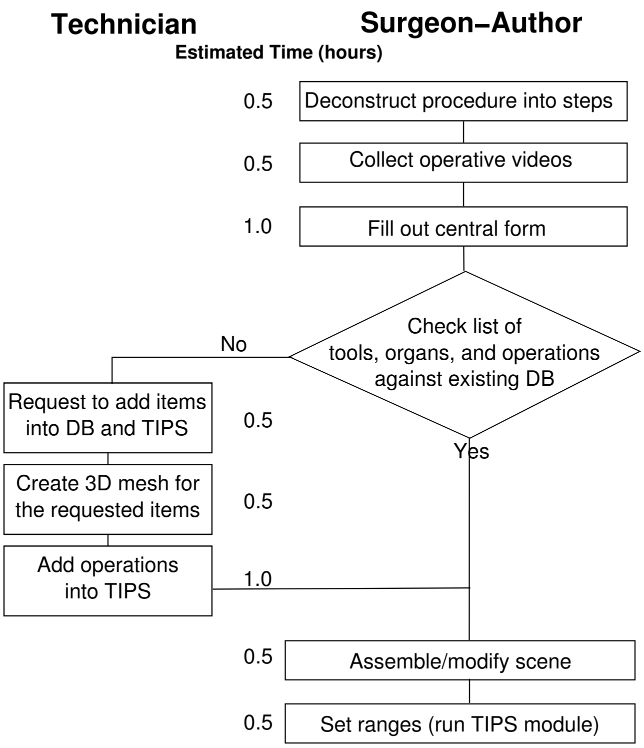
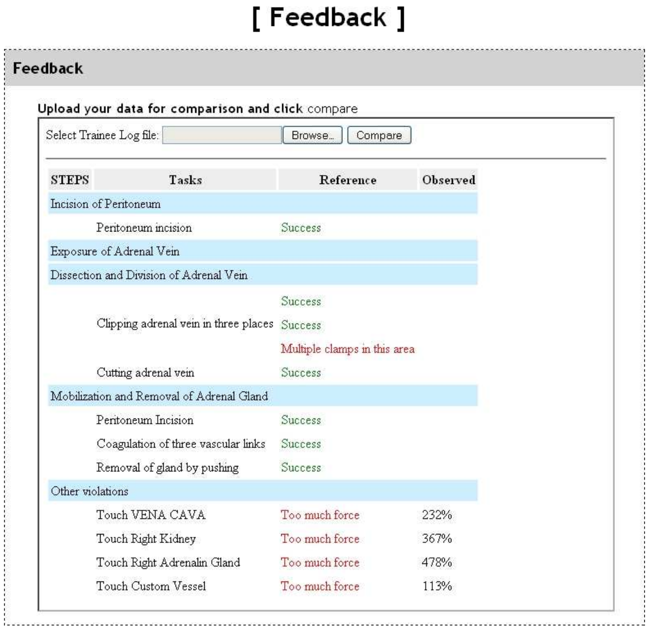


Figure 2: **Authoring effort.** Flowchart and timeline for authoring the appendectomy teaching module.



[Feedback]

Feedback

Upload your data for comparison and click compare

Select Trainee Log file: Browse... Compare

STEPS	Tasks	Reference	Observed
Incision of Peritoneum			
	Peritoneum incision	Success	
Exposure of Adrenal Vein			
Dissection and Division of Adrenal Vein			
		Success	
	Clipping adrenal vein in three places	Success	
		Multiple clamps in this area	
	Cutting adrenal vein	Success	
Mobilization and Removal of Adrenal Gland			
	Peritoneum Incision	Success	
	Coagulation of three vascular links	Success	
	Removal of gland by pushing	Success	
Other violations			
	Touch VENA CAVA	Too much force	232%
	Touch Right Kidney	Too much force	367%
	Touch Right Adrenalin Gland	Too much force	478%
	Touch Custom Vessel	Too much force	113%

Figure 3: **Feedback form.** The trainee's performance is compared to the instructor-set min-max range.

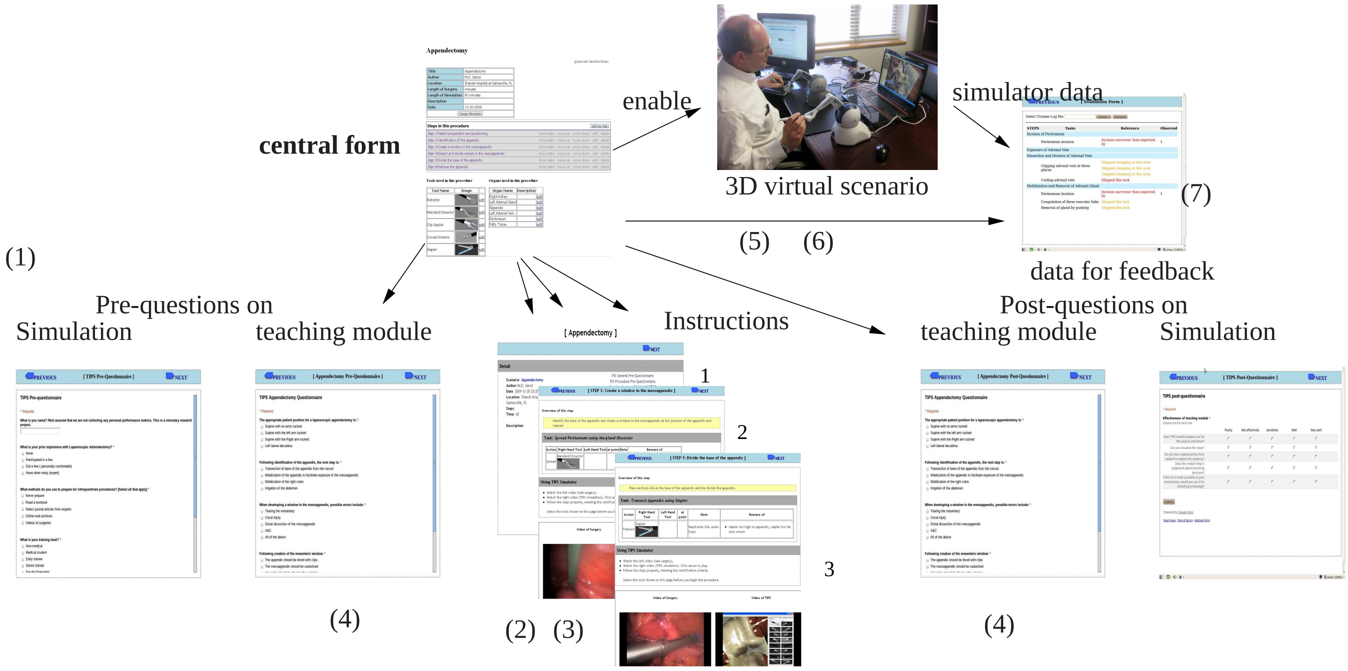


Figure 4: **Auto-generation** of instructions and questionnaires (bottom row of web-pages) based on the central form (see Section 3 for the numbers in parentheses).

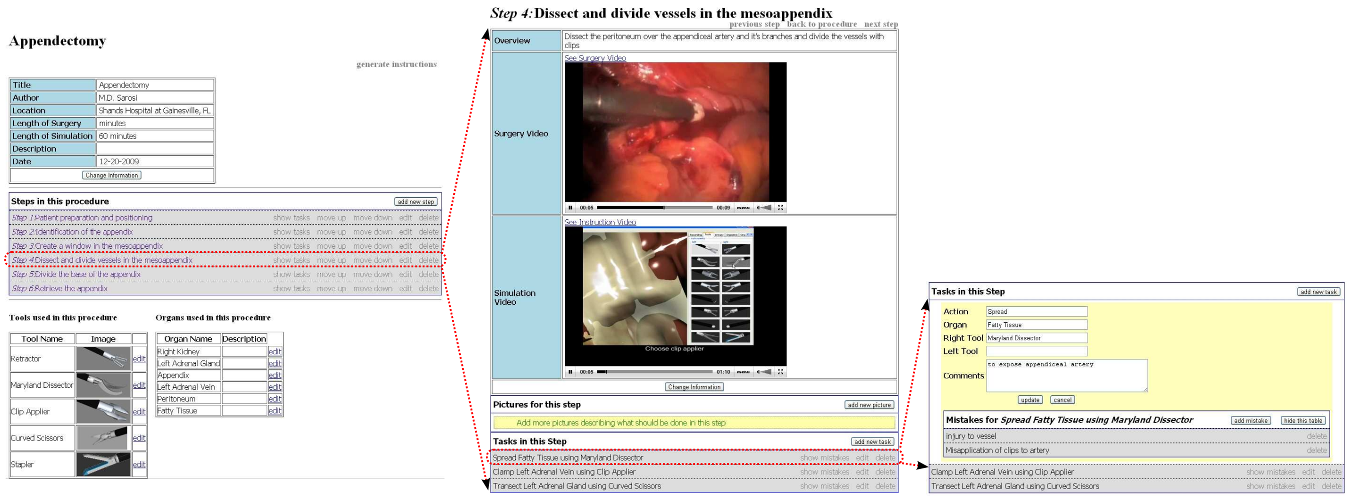


Figure 5: **The central Form** supports a hierarchical decomposition of the procedure and specification of relevant details. (scaling the pdf to 300% allows reading individual entries)