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Research Paper

The potential of digital technologies in problem-based forensic learning activities

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ABSTRACT

Forensic practice is the concluding practical course of the forensic science bachelor program at the School of Criminal Justice of the University of Lausanne. Learning activities are constructed around five main objectives for the resolution of simulated forensic case problems: 1) select relevant traces and items to be collected at the scene and perceive their potential value in the reconstruction process, 2) apply appropriate detection techniques in sequence to obtain clues of good quality, 3) process traces using Analysis, Comparison, Evaluation and Verification (ACE-V) methodology, 4) produce and summarise information in oral and written forms to help an investigation, and 5) work collaboratively to benefit from the diversity of group members. Simulating and supervising realistic activities is a complex task that became more and more challenging with a continuously increasing number of students over the years (from ca. 30 in 2016 to more than 60 in 2021). Thus, an educational innovation project was launched and aimed at implementing digital technologies to support the teaching staff. A computer-based crime scene simulation tool (allowing students to visualize 360° crime scenes and relevant items) and a communication tool (to simplify and centralise the communication between the students and the teaching staff) were implemented. This article describes the implementation, added value and limitations of these digital technologies in problem-based learning activities. Prior to 2020, the practical course forensic practice was delivered entirely on-site without specific technologies, and entirely on-line in 2020 (due to the sanitary restrictions related to the COVID-19 pandemic). Finally, in 2021, on-line and on-site activities were implemented with success, combining the best of both approaches in a blended teaching mode. An overall increase in the satisfaction of students and teaching staff was observed with the implementation of these tools. Limiting presence on-site allowed students to take a step back from the activities and collected items. This promoted critical thinking, and together with an increase in structured (on-line and on-site) interactions allowed for a positive, continuous learning experience. While the evaluations of these novel technologies were very positive, students still expressed their willingness to perform certain tasks on-site and a preference for face-to-face interactions.

1. Introduction

During the forensic science bachelor program at the School of Criminal Justice (University of Lausanne), students acquire theoretical and practical knowledge in forensic science as well as basic knowledge of natural and human sciences such as mathematics, physics, chemistry, biology, computer science, criminology and law[1]. While a range of courses in forensic science focus on specific types of traces[2] [1] (e.g., fingermarks, DNA, digital forensics, questioned documents, drugs of abuse), others cover more transversal subjects such as imaging, microscopy, crime scene investigation (CSI), interpretation and forensic intelligence. Among these transversal courses, the three-year bachelor program ends with a 140 h practical – *forensic practice* – during which students progress through the different forensic aspects of a case investigation. *Forensic practice* is taught in the last 8 weeks of the bachelor program in parallel with other courses, starting immediately

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[1] The detailed bachelor program in forensic science can be found on the website of the School of Criminal Justice of the University of Lausanne: https://www.unil.ch/esc/enseignement/bachelor (last access: September 2021).

[2] A trace is defined here in the forensic science perspective as a vestige or mark of a presence, an existence or an action of someone or something in a location or space that did not belong to that space initially [1].

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after the CSI[3] course. Activities for this course are built around five main learning outcomes:

1) Detect and select relevant traces and items to be collected at the scene based on their information potential (i.e., relevance) in the reconstruction process,
2) Apply appropriate detection techniques in sequence to obtain clues of good quality,
3) Conduct the Analysis, Comparison, Evaluation and Verification (ACE-V) methodology ([2–7]),
4) Produce and organise information to help the investigation,
5) Collaborate with other group members.

Problem-based learning [8,9] combined with experimental learning [10–12] allow students to implement transversal theoretical knowledge and different skills in a practical activity that mimics real case situations (in our case, the investigation of a simulated criminal case). Such learning activities require regular feedback and continuous interactions between students and the teaching staff. As the number of bachelor students has continuously increased over the years (from ca. 30 in 2016 to more than 60 in 2021), the organisation, coordination, and supervision of this course became more difficult to manage with the available teaching resources[4].

To facilitate the supervision and improve the student learning experience, an educational fund was obtained in 2020 from the University of Lausanne Innovation Grant (as of January 2020 - before the sanitary crisis). This educational project called *SimInFo* (Simulation of Forensic Investigation[5]) aimed to implement and rely on digital learning technologies within the *forensic practice* course. In 2020, 360° photography of mock crime scenes and a communication tool were developed and implemented.

The teaching scenario is presented in section 2, while the digital technologies implemented are described in section 3. Section 4 provides a description of the activity along with the feedback and observations made by the students and teaching staff for 3 different periods during which the teaching was performed, i) entirely on-site at the University before the implementation of technological tools (2019), ii) entirely remote (on-line) using digital media (2020), and iii) a blended version combining laboratory (on-site) and computer-based activities, as well as face-to-face and on-line interactions (2021).

2. Teaching scenario

Students work in pairs[6] for the forensic investigation of simulated criminal cases (see Fig. 1). The pairs are placed into four forensic science units (FSUs), with a manager (one teaching-assistant, hereinafter referred to as assistant) and forensic scientists (the students). Depending on the total number of students in the class, each FSU is composed of 4 to 8 pairs of students. The criminal cases are inspired by a wide variety of events such as burglaries, suspicious deaths, or drug trafficking and are prepared by the assistant playing the roles of prosecutor and investigator. This means that the manager in charge of a FSU was not involved in the setup of the cases assigned to the students' pairs that are part of their FSU. This has two main advantages: the manager can freely help students without knowing the actual scenario of the case and potential inconsistencies in the case can be detected and fixed by the manager. The prosecutor/investigator provides external information at different stages of the teaching activity, thus helping students in progressing through the investigation.

The different tasks related to the activity are carried out and evaluated per group or individually. The final grade is based on the evaluation of the different tasks carried out by the students (e.g., pre-assessment, work in the laboratory, final report and oral interview).

While some adjustments have been made over the years, some tasks were proposed every year, such as case pre-assessment, laboratory work (i.e., detection, enhancement, documentation, analysis, comparison, and evaluation), reporting in diverse forms and collaborative work. Some of these tasks are sequential (e.g., pre-assessment, laboratory work and final reporting), while others are iterative (e.g., continuous feedback and collaborative work).

- **Case pre-assessment:** In the first stage, a case pre-assessment is carried out by the students based on the provided information and items transmitted by the prosecutor. For some of the cases, a simulated crime scene prepared by the assistants is also investigated on-site or on-line (see the detailed description of annual specifics in section 4). Based on their observations and available information, students formulate hypotheses about what may have occurred. Using an iterative hypothetico-deductive approach [13], students also select relevant traces and items for further analysis in order to test, eliminate or differentiate the formulated hypotheses in the given context. Finally, students suggest a work plan for their subsequent tasks in the laboratory.
- **Laboratory**[7]: The second stage focuses on the treatment of the seized objects and detected traces. Usually, students have access to the laboratory to perform various tasks including observation with the naked eye and with specific instruments such as microscopes, description, measurement, and photographic documentation of the objects/traces/features. While a large variety of objects and traces (e.g., firearms, drugs, documents, glass, shoe traces, digital forensics, fibres, etc.) may be included in the different cases, almost all students search for fingermarks and DNA. The proposed work plan is adapted to the students' previous knowledge and skills as well as available time, instruments and materials. For example, since some practical stages of DNA analysis (i.e., DNA extraction, quantification, amplification and separation) are taught later in the study plan (during the master's program), students only perform the sampling of the biological traces, which are then sent out for analysis, and receive the results (i.e., DNA profiles). The ACE-V methodology is applied to analyse and then, compare traces and references (e.g., fingermarks, DNA profiles, shoemarks, fibres). The evaluation is also taught later in the program and the information is thus only considered from an investigative perspective [14]. The verification step is performed within or between pairs.
- **Reporting:** Relevant information, received and collected, is continually processed and communicated in oral and written forms to various actors in the teaching scenario (i.e., FSU manager, students and prosecutor/investigator). Final discussions and reporting take different forms (e.g., technical and investigative written reports, oral presentations), and are submitted either individually, per student pair or per FSUs depending on the tasks and the evolution of the learning activity over the years. Final meetings are planned to discuss results with the prosecutor, the FSU manager and, when possible, the teacher.
- **Collaboration:** Collaboration and interaction between students as well as with the teaching staff are necessary for the majority of the tasks. While students consistently work in pairs, collaboration with other students is usually also required as some of the investigated cases within a FSU are intentionally linked. The whole class is also encouraged to collaborate when different pairs are working on the same type of case,

[3] The theoretical and practical course "crime scene investigation" (CSI) is taught and evaluated separately. Thus, students start "forensic practice" with good CSI basic knowledge.

[4] A four teaching-assistants team, supervised by a teacher, evolve on a quasi-yearly basis. New team members regularly need to be updated and integrated in the teaching staff, while experienced assistants leave.

[5] Translated from the French "Simulation d'Investigation Forensique". An illustrative video of the project is available on youtube (in french only): https://youtu.be/7vLBKnW-qY4.

[6] A three-person group is created when the number of students is odd.

[7] In 2020, due to the COVID-19 pandemic restrictions, all activities had to be performed on-line including "laboratory" tasks.

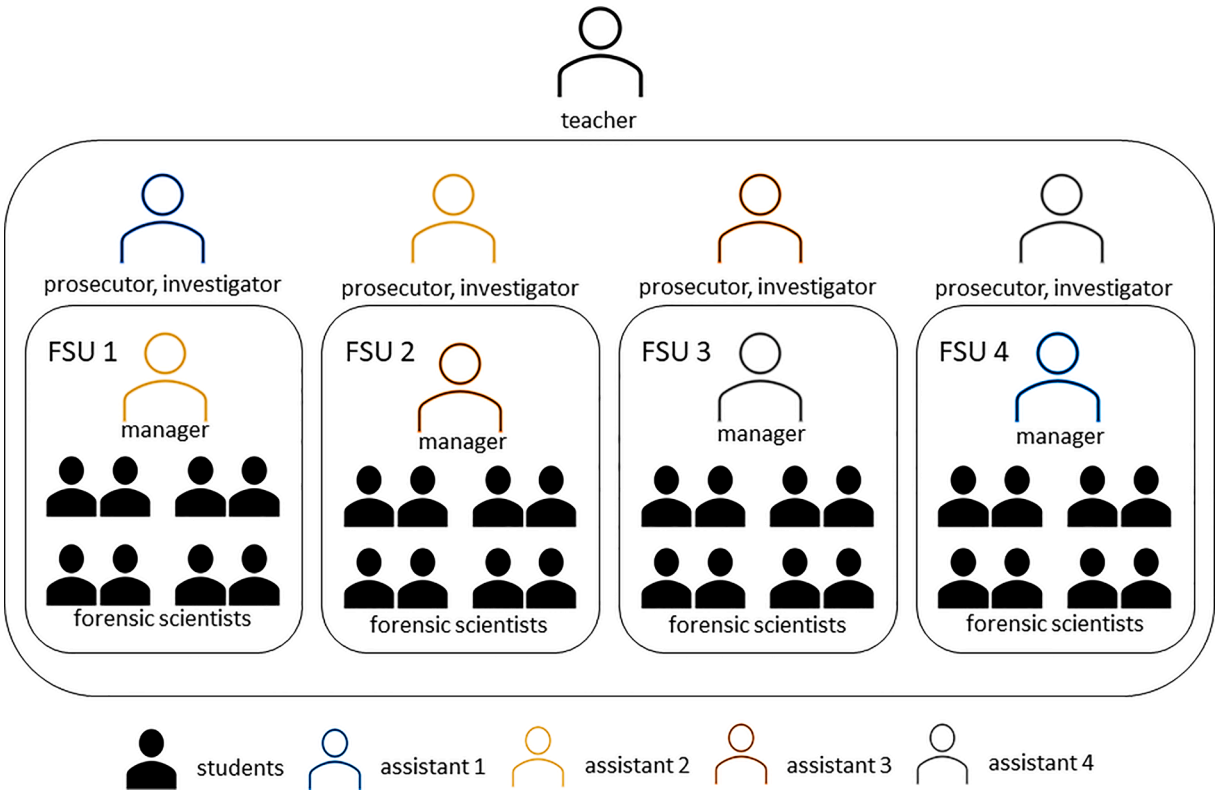

Fig. 1. Schematic representation of the organisation of forensic practice: Students are divided in four forensic science units (FSUs) supervised by one assistant playing the role of FSU manager. A second assistant also interacts with the students in the role of prosecutor and investigator. Students collaborate in pairs, but also with the other students in their FSU. A teacher supervises and coordinates the four assistants.

objects, or traces. For example, students share the preparation and use of chemical solutions and test objects in the laboratory. Students also need to collaborate with the teaching staff. In addition to spontaneous exchanges, several meetings are organised. Some occur between the pair members and their manager, while other larger coordination meetings are conducted for a whole FSU in the presence of the manager and the prosecutor/investigator. During these interactions, assistants avoid being too prescriptive and provide advice, guiding student reflection. For example, assistants may ask questions such as "What traces do you propose to look for?" and "Why do you propose to search for these traces?"

3. Digital technologies

Digital learning is defined as any type of learning that is facilitated by technology or by instructional practice that makes effective use of technology [15]. In the context of the practical course *forensic practice*, technological tools were implemented to digitise some activities such as the examination of simulated crime scenes and to improve/facilitate communication (see Fig. 2).

3.1. Computer-based crime scene examination

Digital working material such as high dynamic range (HDR) 360° photography of the crime scene, scans of documents and pictures of objects and of traces were created by the assistants or collected from former practical courses. HDR 360° images of the crime scenes were captured using SceneCam® camera (SpheronVR AG, Germany) and edited using SceneCenter® forensic software (Version 1.5, SpheronVR AG). The editing process allows to highlight objects not visible on the captured environment (such as the shoemark highlighted in Fig. 2 by a yellow marker) and to provide a close-up view of specific objects/traces (such as the medical prescription in Fig. 2). The other digitised materials were created using desktop scanners and digital photography cameras.

The main objective of this panoramic technology was to prepare complete virtual crime scene environments that each student could investigate remotely, thus enabling the replacement of the on-site mock CSI activities that took place before 2018.

3.2. Digital communication

An open-source, self-hosted on-line chat service with file sharing (Mattermost™) was configured by the IT support specialists. "Teams" and "channels" were created to allow, on one hand, students to contact their FSU manager and prosecutor/investigator (roles played by the assistants) and, on the other hand, teaching staff (the four assistants and the teacher) to manage and follow the different pairs under supervision. For that purpose, one "team" was created for each pair of students with two "channels": the first channel for the communication between the students and their prosecutor, the second one for the exchanges between the students and their FSU manager. With full access to all "teams" and "channels", the teacher in charge of the practical course can have a full and clear overview of the activities both at the pairs and at the FSU level, even when not involved on a daily basis in the activity. Being accessible via computers and mobile phones, this application facilitates remote communications as much as exchanges initiated from the office or the laboratory.

In addition to written exchanges, on-line oral exchanges via video conferences were also implemented. The software Webex (Cisco®) and Zoom (Zoom Video Communications, Inc.) were used in 2019 and 2020, respectively.

4. Observations over 3 academic periods

To evaluate the advantages and difficulties in the implementation of digital technologies within problem-based learning activities, we have

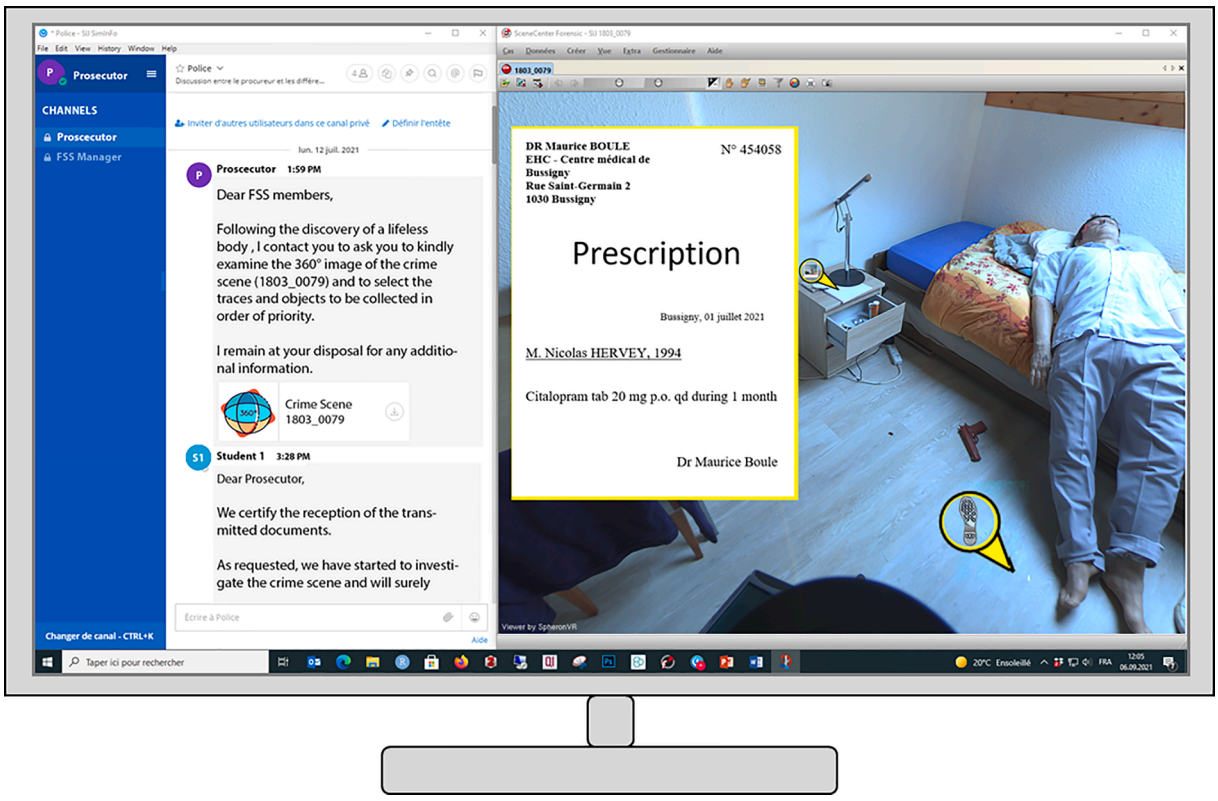

Fig. 2. Schematic illustration of the main implemented digital tools: (left) An instant messaging application for communication and (right) a computer-based simulation of a mock crime scene (360° view). Objects and traces can be highlighted on the scene using yellow markers, e.g. medical prescription on the bedside table and a shoemark on the floor near the foot of the deceased (note that the person is a mannequin, not a real human being).

compared the practical course *forensic practice* that has been held before 2020 (entirely at the University without using specific digital media), in 2020 (entirely remotely using digital media) and in 2021 (blended mode with on-site and remote tasks). Every year, small adjustments were made to improve the learning and teaching experiences based on student feedback and observations made by the teaching staff. Additional changes were made in order to adapt to circumstances specific to the time period, e.g., limited laboratory space due to a higher number of students or restrictions due to COVID-19 pandemic. Thus, the implementation of digital technologies is also discussed considering the possible impact of other changes between 2020 and 2021.

A brief description of the specificities of each period is followed by the feedback from students and the observations from the four assistants and the teacher. The evaluation of the practical by students has been organised by the University of Lausanne Teaching Support Centre. Feedback from students was obtained using a structured survey (via paper or on-line questionnaire) containing "do you agree or disagree" questions (Likert scale, see supporting information SI-1). The surveys were entirely anonymous and the data protection charter from the Teaching Support Centre specifies that the collected data can be used for educational research purpose.[8]

Only the questions that were asked each year and that were considered as directly related to the subject of this manuscript have been considered in detail, while other questions are only briefly addressed (such as clarity of objectives, guidelines, structure of the course or assessment criteria). The analysis of the results (responses) to five selected questions allowed for the evaluation of the level of student satisfaction[9], specifically:

- Adequate resources were available to perform the expected work.[10]
- Workload was appropriate in relation to the number of credits given.
- You received satisfying answers to your questions.
- You have acquired new skills.[11]
- Overall, you appreciated this practical.

The average satisfaction to all questions was calculated. In 2020 and 2021, additional questions were integrated to evaluate the implemented digital technologies and the on-line teaching, in general.

The survey also included open-ended questions about the positive aspects of the course, possible improvements and additional comments. Comments expressing a similar idea, even if worded differently, were manually gathered into a response category. The number of comments

[8] Charter available using the following link (last access: March 2022): https://unil.ch/files/live/sites/evaluation/files/documents/Charte_de_traitement_des_donnees_V2.pdf.

[9] The answers "agreed" or "somewhat agreed" were pooled together as "agreed", while the answers "disagreed" and "somewhat disagreed" were pooled together as "disagreed". The percentages of agreement and disagreement were calculated using the sum of agreement and disagreement, without taking into account the "empty" answers (as advised by the Teaching Support Center).

[10] In 2020, the question was formulated slightly differently, using the statement "An adequate study environment was available to perform the expected work."

[11] In 2020 and 2021, the question was formulated differently, using « You have achieved significative learning ».

in a category were then used to better identify positive aspects, as well as elements that still need improvement.[12]

4.1. On-site without specific digital technologies (2016–2019)

4.1.1. Description

From 2016 to 2019, *forensic practice* has constantly evolved to improve the learning experience of the students considering yearly specificities such as the number of students and available laboratory space. Before 2020, most tasks and all meetings were performed on-site. Some communications between the students and the teaching staff were still in paper form, while digitisation was limited to exchange of emails, pdf and image files. Students worked successively on two cases with the objective of improving their competences through continuous feedback across their reporting activities for the two cases. One of the cases was linked (through detected traces) to other cases investigated in the same FSU to stimulate collaborations. While on-site mock crime scenes for the first case were prepared before 2018, the second case was based on objects and traces transmitted by the assistants together with contextual information. Due to the increased number of students in 2018 (57 vs. 33 in 2017), the crime scene investigation was removed and the amount of time in the laboratory was halved when compared with previous years. In 2019, despite the relatively low number of students (38), no crime scene examination was planned in anticipation of the higher number of students expected in following years (57 in 2020 and 64 in 2021) and students again had full access to the laboratory. Each students' pair submitted two written reports (one per case), while a third report on the detected series (in team of 8 to 10 students) was submitted by each FSU. Students had one final oral exam (individually) in the presence of two assistants (FSU manager and investigator/prosecutor) alongside the teacher.

4.1.2. Student feedback

Despite a relatively high overall satisfaction of the students in 2019 (average agreement rate for all statements of 78%), only 60% of the students that answered the survey (22/38) reported having appreciated the course (see Fig. 3 and Table 1). Students agreed that adequate resources were available (90%) and that they acquired new skills (86%). However, only 68% stated having received satisfactory answers to their questions and only 57% agreed that the workload was appropriate. While 4 students stated in their comments that the workload was too heavy, 4 confirmed having sufficient time to perform the tasks showing a divided opinion on the workload aspect. This may be both due to differences in the perception of the students, and different effective workloads between the distributed cases. Indeed, the teaching staff previously noted the difficulty of preparing balanced cases, particularly as students do sometimes encounter unexpected difficulties with some items and traces.

The analysis of the students' comments also highlighted that students especially appreciated the application of previously acquired knowledge through independent work for the resolution of practical cases drawn from real situations (16 comments). Nine comments highlighted recurrent communication and coordination problems (also noted by some students in previous years).

4.1.3. Observations of the teaching staff

Excluding the CSI part in 2019 reduced the complexity of the course but introduced additional problems. It demanded more imagination from both assistants and students, and led to confusion and issues in the comprehension of the cases. While CSI was still deemed important by the teaching staff to simulate a more realistic context for the students, all agreed that it required too much preparation and supervision to be continued with the increasing number of students. On the other hand, the statements and comments about heavy workload were traced back to the time the students spent in the laboratory which was considered as too high compared to the time dedicated to critical thinking and reporting. Thus, to address both CSI and laboratory workload issues, it was decided for the next year, to firstly develop and implement a crime scene imaging tool for the case-preassessment stage, and secondly, to limit the time students spent in the laboratory in order to give them more time for other important tasks.

Regarding communication, the teacher found it difficult to have a clear overview of the numerous interactions between the students and assistants. The assistants also felt that many (often unexpected) questions were continuously asked by the students and that there were difficulties coordinating answers between FSUs. Thus, the implementation of a centralised communication tool along with the integration of computer-based mock crime scene examination seemed to be a favourable solution for the *forensic practice* course.

At this stage, the teaching staff still felt that two cases were necessary to allow for a continuous learning experience improved by an intermediary feedback.

4.2. On-line using new digital tools (2020)

4.2.1. Description

In 2020, a total of 57 students divided into 28 pairs participated in the practical course. Due to the sanitary situation, all activities had to be carried out remotely – including communication. Thus, the students and the teaching staff were in contact throughout the entire practical *via* Mattermost and video conferences. Each pair worked on only one case to reduce management complexity, for both the teaching staff and the students. Using the crime scene simulation tool, activities started with an examination of the crime scene using the 360° images prepared by the assistants (see example in Fig. 2). Along with the contextual information received from the prosecutor/investigator and from their observation of the computer-based crime scene, students were asked to formulate hypotheses about the reconstruction of the events and propose a list of priority items and traces to be collected and analysed. This activity replaced the on-site mock CSI carried out before 2018. This preassessment was submitted in the form of a 2-page written document per students' pair followed by a presentation *via* video conference. To begin the "laboratory stage", each pair of students received a list of items to work on. Seized items were transmitted as digital material, mainly photos or scans. Per pair, students were asked to outline a suitable methodology for the analysis of each item, i.e., to propose a plan including the manipulations/analyses to be performed and in which sequence they should be performed. This task was detailed in a written report. Images of traces and references were transmitted in digital form to the students, who were then asked to proceed following the ACE-V methodology. Results were presented and discussed in a final report (per pair) and discussed individually in a final oral interview in the presence of the two assistants (FSU manager and investigator/prosecutor). The teacher participated in several of the interviews.

4.2.2. Student feedback

Compared to 2019, student satisfaction regarding most of the statements increased despite the fact that the entire activity was performed remotely using digital technologies (see Fig. 3 and Table 1). The average agreement rate for all statement reached 87%, while 93% of students that answered the survey (46/57) reported having appreciated the course. Most students, again, agreed to have acquired new skills (89%), while 98% stated having received satisfactory answers to their questions. 84% agreed that the workload was appropriate, with 3 students having commented that that the workload was too high, and 4 having found that the workload was unequally distributed between tasks.

Only the resources were deemed less adequate than in the previous year. Indeed, only 79% of the students agreed with the statement "the

[12] In this paper, only the comments related to the selected statements or the introduction of digital technologies are discussed in particular.

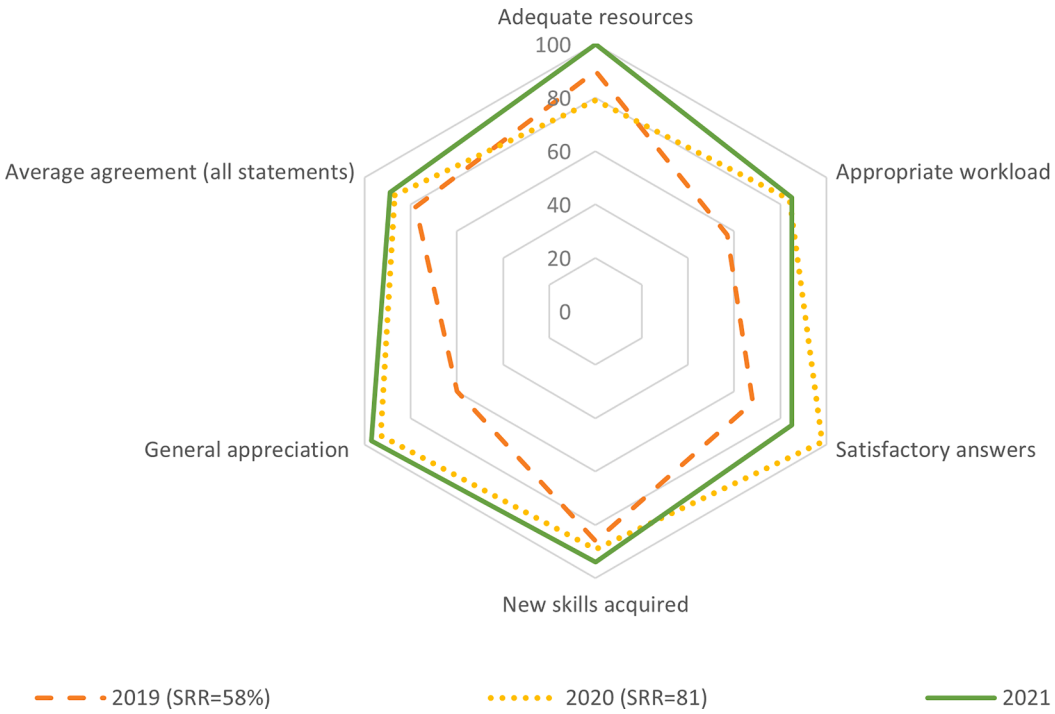

Fig. 3. Radar plot of student satisfaction (percentage of "agreed" and "somewhat agreed" answers) in 2019, 2020 and 2021. The survey response rate (SRR), which corresponds to the percentage of students that answered the survey, is indicated next to each year.

Table 1
Percentage of students that "agreed " and "somewhat agreed " with the 5 selected statements and average agreement rate (all the statements) for each compared year. The criteria are considered sufficiently fulfilled when a satisfaction above 80% is reached for one question (marked in green). The SRR (number of answers/number of students) is given with each year.

Criteria	2019 (SRR=22/38)	2020 (SRR=46/57)	2021 (SRR=36/64)
Adequate resources	90	79	100
Appropriate workload	57	84	85
Satisfactory answers	68	98	85
New skills acquired	86	89	94
General appreciation	60	93	97
Average agreement (all statements)	78	87	89

learning environment allowed them to carry out the planned work". Together with the students' comments, this indicated that some on-site activities, particularly in the laboratory, would have been appreciated.

The students' other comments confirmed that the on-line version of *forensic practice* still allowed the application of previously acquired knowledge through independent work for the resolution of practical cases drawn from real situations (7 comments against 16 in 2019).

Overall, 84% of the students declared having been comfortable with the distance operation of this teaching. 98% of the students agreed with the statement "Mattermost allowed communication in a satisfactory manner". This may partly explain the increased agreement of the students about receiving satisfactory answers to their questions (98% in 2020 vs. 68% in 2019), as the use of this tool allowed the centralisation and improvement in the structure of communication. Despite some technical issues (5 comments in the open-ended questions) and improvement possibilities (2 comments), students stated that Mattermost worked well, was easy to use (6 comments), and that it would also be useful during on-site activities (1 comment).

Regarding the digitised crime scene examination, most students agreed with the statement that "the 360° image of the crime scene allowed for performing the expected tasks under good conditions" (96%) and that "their reflection was stimulated by the 360° images of the crime scene" (77%). Some students also indicated that the planned activities further stimulated their reflection (4 comments). Regarding the question of the "added value" of a digitised crime scene compared to laboratory work, 42% of the students disagreed, indicating their wish to have some on-site activities.

For the decrease in workload, even if the use of a digitised crime scene may have played a role, other factors may be involved, such as no practical laboratory work where only one case was investigated per pair without links between the FSU cases. The results may have also been affected by the exceptional situation. As all teaching activities had to be transferred on-line, students may have been more tolerant than usual about some issues. Interestingly, a higher percentage of students answered the survey than usual (81 % in 2020 compared to 58% in 2019 and 56% in 2021).

4.2.3. *Observations of the teaching staff*

The use of 360° crime scene photography together with the communication tool extended the learning environment, allowing both students and assistants to work remotely from home (distance learning[13]). In practical terms, the use of digitisation offered the

[13] Distance learning, even if variably defined and used in the literature, refers to teaching activities during which the interaction that occurs between the learners and supervisors is held at different times and/or places, independently of the forms of instructional materials (i.e. print or electronic media) [3].

possibility to perform, despite restrictions due to the pandemic, all the activities within the teaching scenario, including crime scene examination (using 360° images of the scenes) and simulated laboratory work (using images of objects, traces and analysis results). Computer-based crime scenes appeared as an interesting solution to cope with the high number of students, while ensuring them an adequate insight into a crime scene. Moreover, working with images rather than with real on-site scenes and objects, provided students with more time for thinking in a less stressful environment. For the assistants, digitised scenes allowed saving time, first, because the same mock crime scene can be used to generate several computer-based crime scenes; for example, by changing the objects visible in the scene or by moving the mannequin before recapturing another 360° image. Second, the same digitised crime scene can be used for different cases by highlighting different details and traces in the 360° image and by providing students with various scenarios. Finally, these 360° images of crime scenes can be stored on a centralised server providing a database of computer-based mock crime scenes that can be reused in following years. Thus, while digital technologies cannot entirely replace practical activities, such as the handling of objects and traces in the laboratory, they can still be useful to plan and discuss the analyses to be performed[14]. However, a virtual laboratory required much more time and effort from the assistants because images from traces and objects needed to be created (or searched for from previous year's materials).

Regarding the use of Mattermost, while it facilitated the supervision and communication with the students, it also allowed constant contact – anywhere and anytime – between the students and the teaching staff. Thus, limits regarding the availability of the staff needed to be clearly defined (e.g., for example only during the teaching time specified in the course schedule).

The teaching staff concluded that a blended system combining computer-based tasks and on-site manipulations of objects and traces in the laboratory would be an ideal solution for *forensic practice*. This was tested in 2021 as the sanitary situation allowed for some activities to be carried out on-site.

4.3. Blended mode with digital technologies (2021)

4.3.1. Description

In 2021, activities were organised similarly to the previous year with two main differences: 8 students worked on the same case and, thus, on the same computer-based mock crime scene, with some laboratory tasks carried out on-site. The entire class (64 students) was sub-divided 1) in pairs (working closely together), 2) in teams of 8 students (working on the same case), and 3) in a FSU of 16 students (2 teams supervised by one manager and one prosecutor/investigator).

Eight crime scenes were prepared and digitised. As in 2020, case pre-assessment was carried out entirely remotely. Students accessed their digitised crime scene on-line and were asked to formulate hypotheses about the reconstruction of the events as well as to propose which items to collect and for which traces to search. They worked in pairs for this task but were allowed to consult with other members of their team (i.e., the other students working on the same scene). A presentation was prepared by each pair of students and discussed during a video conference meeting with the team of 8 students, the FSU manager and the prosecutor/investigator. Each pair of students received between 2 and 4 objects or traces. After a period of reflection, students participated in a video conference with their FSU manager where they proposed a sequence of analysis and/or treatments prior to working on-site in the laboratory. Because the sanitary situation only allowed for a limited part of the practical activities to take place at the University, 20 h of laboratory were organised on-site, alternating between the four FSUs. Although face-to-face interactions with the FSUs managers did take place during the laboratory sessions, most of the communication occurred *via* Mattermost throughout the practical. At the end of the practical, another team meeting was organised to pool and discuss results obtained for all objects and traces seized on a case (i.e., for the 8 students working on the same case). Results were presented in a technical report (per pair) and in a case discussion report (per team). A final oral interview with the FSU manager and investigator/prosecutor occurred for each students' pair.

4.3.2. Student feedback

Forensic practice taught in blended mode resulted in the highest average satisfaction rate since 2019 (see Fig. 3 and Table 1). Student satisfaction regarding most of the statements were higher or similar compared to the previous time periods, and for the first time all statements in Fig. 3 (and Table 1) reached more than 80% agreement. The average agreement rate for all statement reached 89%, while 97% of the students that answered the survey (36/64) reported having appreciated the course. All students agreed that adequate resources were available (100%) while most agreed that they acquired new skills (94%) and 85% agreed that the workload was appropriate. Only one (positive) comment regarding the workload was received, demonstrating that a good balance was achieved in 2021, even though some students still felt that there were some differences in the workload between pairs (12 comments). Finally, 85% of the students agreed to having received satisfactory answers to their questions.

Overall, 97% of the students declared that they were "comfortable with the distance delivery of this teaching" and 94% agreed with the statement "the technological choices […] deployed in this teaching allowed you to follow the teaching under good conditions". Again, Mattermost and video conferencing were considered by the students to be well suited as a means of communication (12 comments and 5 comments, respectively). These results indicate that the implemented tools were also appreciated in a blended version of the practical.

A major improvement was observed in the learning environment, with all students who provided a response (35/64) agreeing that "adequate resources were available to perform the expected work". This increase, compared to previous years (including 2020), confirmed the observations of the teaching staff that laboratory work is an essential part of the practical that cannot entirely be replaced by digital technologies. It also indicated that limiting access to the laboratory freed up time for other essential tasks (e.g., formulating hypotheses, designing the analyses to be performed, and processing and reporting the obtained results).

The positive aspects highlighted previously (see sections 4.1 and 4.2) were still appreciated by students in 2021: application of theoretical knowledge through independent work using problem-solving approaches through realistic scenarios (19 comments) and activities stimulating the reflection (1 comment).

4.3.3. Observations of the teaching staff

A blended teaching mode, combining a computer-based crime scene examination with on-site laboratory work, was perceived as a balanced approach to achieving high quality teaching to a larger number of students with limited resources (regarding available time, space and assistants). Decreasing access to the laboratory had an overall positive impact since a large part of the stress felt by students seemed to come from an inadequate management of their time. Regulating access to the laboratory – together with the computer-based crime scene examination – allowed students to be more efficient and freed up time for reflection and reporting, thus increasing the overall quality of their work.

Thanks to the increased number of meetings between assistants and students (and the possibility for more continuous feedback), it was concluded that one case per pair was actually sufficient.

[14] It is important to keep in mind that most of the practical skills implemented in forensic practice have already been acquired in previous courses. Thus, an emphasis on the critical thinking compared to practical skills is useful in such a context.

The use of Mattermost facilitated communication when the work was performed remotely while remaining compatible and useful when tasks were performed on-site. However, combining on-line and on-site activities further complicated the coordination between the different FSUs and between the members of the teaching staff, as they were not always on-line or on-site at the same time (due to the alternating occupation of the laboratories by the different FSUs).

Moreover, large meetings via Zoom did not allow for the same level of interaction than can be achieved in person (face-to-face). Such meetings required more structure and planning in advance. Combining the same level of planning with meetings in-person may be very useful for the continuous improvement of interactions and communication within *forensic practice* in future years.

5. Conclusion and perspectives

Designing and implementing realistic forensic case simulations is a complex teaching task, particularly when it involves a large number of students and limited available resources (i.e., teaching staff, space, and time). Despite continuous adjustments over several years (2016–2019), some recurrent problems were faced by the teaching staff of *forensic practice*, mainly, a high workload for students and assistants and difficulties in coordination and communication.

To overcome these difficulties, the educational project called *SimInFo* was launched to implement digital learning technologies to ease the teaching tasks and increase the learning experience for students. Thus, in 2020, a 360° mock crime scene photography tool and a communication tool were developed and implemented. The outcome of these new on-line activities was positive on several aspects as highlighted by the students' feedback and observations made by the teaching staff. The overall satisfaction of the students exceeded 80% for the first time in 2020 and 2021. This was observed both when asking the students directly and summing up the average satisfaction across all statements. Student satisfaction regarding workload and communication also significantly improved.

The 360° crime scene photography tool allowed students to step back from the stressful environment of a crime scene and freed up time to think of what might have happened (i.e., formulate hypotheses) as well as to develop strategies for their scientific investigation (i.e., come up with a work plan before starting practical work). In 2020 (when all the activities had to be carried out remotely), both the students and teaching staff felt that some laboratory tasks would have been welcomed for a more balanced and realistic learning experience. Thus, a blended version was implemented in 2021 resulting in very high satisfaction levels among students, particularly regarding the adequacy of resources at their disposal. In addition, the centralised communication tool allowing messaging (i.e., Mattermost), first facilitated the supervision and communication and second helped coordinate answers given to the students throughout the practical. In conclusion, digital technologies were effectively implemented to support student autonomy and collaborative activities while maintaining learning quality.

Some drawbacks of the implementation of digital technologies within problem-based activities were also observed. Regarding the 360° crime scene simulation tool, the main disadvantage was a reduction (or absence) of physical manipulations, which are important for the acquisition of practical skills. Additionally, digital technology (in this context) creates a disconnection/distancing from the reality of a crime scene, both in terms of limited point of view (e.g., one cannot look under the bed or through the window) and the experience in real time. Indeed, the stress felt by the students when attending a real rather than virtual (even if simulated) crime scene is an important part of the teaching. Thus, a computer-based representation of a mock crime scene is insufficient for learning all aspects of crime scene investigation, but allows for preliminary exploration (e.g., pre-assessment exercise) and contextualisation to develop further skills (e.g., contextualised laboratory work). Regarding communication, messaging and video conference tools cannot entirely replace face-to-face exchanges. They require more concentration and do not convey more subtle body language. They can also induce some stress in the participants for example due to the expectation of immediate answers and the risk of backlog as students tend to quickly accumulate questions (forgetting that the teaching staff has to deal with demands from a higher number of sources). Finally, interactions, particularly in a larger meeting, are better in person than on-line.

Moreover, some improvements cannot be achieved through digital tools and still need to be worked on, such as clearer guidelines and evaluation criteria. Thus, digital technologies, adequately combined with human pedagogical skills, allowed for improving the academic teaching and learning experience of *forensic practice*, particularly when dealing with a large number of students with limited available teaching resources. A blended version was considered, by both the students and the teaching staff, to be the ideal solution in reducing complexity, while maintaining realistic problem-solving and experimental learning. In future years, the plan is to increase on-site activities (particularly team meetings and interactions), while retaining the 360° crime scene simulation for case pre-assessment, along with the messaging tool to coordinate and keep track of the communication between students and teaching staff.

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CRediT authorship contribution statement

Natalie Kummer: Conceptualization, Funding acquisition, Data curation, Project administration, Writing – original draft. **Olivier Delémont:** Conceptualization, Funding acquisition, Writing – review & editing. **Romain Voisard:** Conceptualization, Funding acquisition, Writing – review & editing. **Céline Weyermann:** Conceptualization, Funding acquisition, Data curation, Writing – original draft.

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