Innovative Learning Technologies as Support to Clinical Reasoning in Medical Sciences: The Case of the "FEDERICO II" University

Oscar Tamburis[1(✉)], Fabrizio L. Ricci[2], Fabrizio Consorti[3], Fabrizio Pecoraro[2], and Daniela Luzi[2]

[1] Department of Veterinary Medicine and Animal Productions, University of Naples Federico II, 80137 Naples, Italy
oscar.tamburis@unina.it

[2] Institute for Research on Population and Social Policies, National Research Council, 00185 Rome, Italy
{f.ricci,f.pecoraro,d.luzi}@irpps.cnr.it

[3] Department of Surgical Sciences, Sapienza University of Rome, 00185 Rome, Italy
fabrizio.consorti@uniroma1.it

Abstract. The paper describes the first deployment phases of the HIN (Health Issue Network) approach as innovative learning technology for both the Departments of Veterinary Medicine and Animal Productions and of Public Health of the "Federico II" University of Naples. To test this approach, the researchers involved were called to translate clinical cases from their professional experiences by means of a friendly version of HIN's Petri Nets-based formalism, called f-HINe. A specific software learning environment (fHINscene) was also tested, which allows drawing a f-HINe diagram, as well as designing clinical exercises for medical students according to the Case-Based Learning approach. The results of the tests proved the importance of having a synthetic graphic representation able to analyze complex clinical cases and encouraging inquiry-based learning methods.

Keywords: Human medicine · Veterinary medicine · HIN · f-HINe · Innovation · Learning technology

1 Introduction

Students of medical classes are required to reach the end of their curricula with a level of competence that makes them capable to address clinical practice as early as possible. Medical professionals are requested as well a continuing education, to be constant active players in the community setting. The Dreyfus model [1] describes the structure of the learning process, and features students and early postgraduate physicians in the lowest rankings levels. They need therefore a rich and challenging simulation environment based on real/realistic clinical

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cases that integrate theory and practice to explore and understand the issues, identify problems, and make decisions. This context suffers from the lack of: (i) real/realistic clinical cases reflecting the case-mix of the "epidemiological transition"; (ii) teaching methods that allow the learner to analyze the evolution of a patient's health issue. Moreover, education and professional development need to be linked to the ability to competently practice medicine within changing and evolving health care systems: new knowledge and skills are necessary to develop unique and iterative approaches to addressing medical problems. In this scenario the Petri Nets-based Health Issue Network (HIN) approach [2–5] has been designed to support teaching and learning activities for medical sciences, so a learner can: (i) browse a clinical case over time; (ii) train to detect the interactions and the evolutions of the health issues; (iii) represent, via the use of diagrams, different kinds of clinical cases in a synthetic way; (iv) develop the ability of clinical reasoning over time. A lighter version of HIN, named f-HINe, was developed to: (i) provide users with a "friendly" tool to handle the evolution of a patient's health status instead of Petri Nets formalism as such, although based on the same mathematical properties [6]; (ii) design networks reproducing teacher-designed realistic clinical histories or clinical stories related to a real, specific subject, "extracted" from a veterinary/electronic health record (V/EHR) to meet specific learning objectives [7]; and (iii) support an automatic assessment of the learner's performance during the execution of the clinical exercises.

The present work shows the first results of a project focused on the implementation of f-HINe as innovative learning technology for researchers of both human and veterinary classes within the "Federico II" University of Naples.

2 Materials

Several didactic methods are reported in the literature focusing on the education of health sciences students, among which are the following:

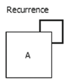
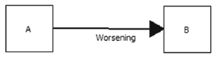
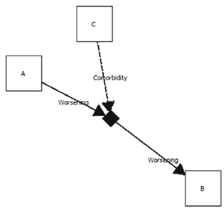
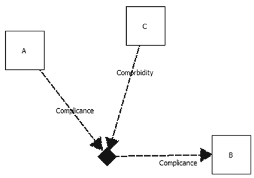
- Didactic methods based on expert patients. The "patient expert" and the "patient trainer" are both figures who have lived or are living a given pathological condition and then possess the skills to lead doctors, students, social and health workers to acquire a thorough knowledge of the disease as well as its related problems;
- Didactic methods based on the use of predefined questions. The International Comorbidity Evaluation Framework, or ICEF, was developed to timely introduce in the training programs of future physicians the concept of comorbidity, intended as *"a morbid condition that, more than the others, causes a worsening of an individual's health status"* [9]. The effectiveness of the ICEF method is especially relevant when applied in association with CBL, as ICEF supports the integration between an abstract model and the simulation of a real clinical practice;

- PBL/CBL - based didactic methods. Contemporary educational methods such as Problem-Based Learning (PBL) and Case-Based Learning (CBL) are being increasingly recognized as important research topics in medical science education. CBL in particular, making use of real/realistic clinical cases links theory to practice through the direct application of theoretical knowledge to the cases themselves and encourages the use of inquiry-based learning methods [10].

3 The f-HINe Model

A Health Issue (HI), or clinical condition, can be a disease hypothesis, a sign/symptom, a diagnosis, a risk factor, or any other piece of clinical information. A HI network (HIN) describes the health status of an individual throughout his/her life. It is therefore capable to highlight how e.g.: (i) clinical conditions have changed over time; (ii) the interactions between different conditions have influenced their evolutions; (iii) a treatment plan for a specific condition may have changed into a structured treatment pathway. A clinical condition in the HIN model can: (i) evolve (spontaneously or after treatment) either to improve or to worsen; (ii) generate (although remaining active) other clinical conditions as a complication/cause, or catalyse the evolution of another problem as co-morbidity; (iii) relapse after resolution. A clinical condition can also trigger an in-depth examination, which points out the passage from: (i) a symptom to a diagnostic hypothesis/a diagnosis; (ii) a diagnostic hypothesis to a specific diagnosis, by means of a diagnostic test; (iii) a diagnosis to another one, in the case the first one turned out to be incorrect. Compared to HIN's PNs-based graphs, the f-HINe origins diagrams composed by nodes (HIs) and edges (evolutions from input HIs to output HIs). Edges can be drawn via: (i) a solid line, when evolutions do not affect or alter HIs' nature (e.g. recurrence, worsening, improvement, examining in-depth); (ii) a dashed line, in case the evolution of a HI implies the generation of a new HI (e.g. complication, cause). A static branch node (or aggregator) can be used in case of more than one input HIs and/or output HIs involved in the same evolution: it is the case of e.g. a worsening or a complication in presence of a co-morbidity. The possible persistence of one or more conditions over time can lead to the design of another primitive, depicted as a thick edge that connects the same duplicated HI. Evolutions are therefore always labelled, and their related descriptive data sheets report information about the activities performed during the diagnostic-therapeutic process. The whole set of activities associated to the evolutions sets forth the actual treatment process the patient has undergone. Table 1 shows the main graphic primitives of the f-HINe model, along with specific clinical examples.

Table 1. Graphic representation of the main f-HINe primitives

Type of evolution	**f-HINe primitive**	**Examples**
Recurrence		Recurrent episodes of acute diverticulitis (*A*)
Worsening / Examining in-depth / Improvement		A 2nd degree kidney failure (*A*) worsened into a 3rd degree (*B*)
Complication / Cause		Diabetes (*A*) complicates with a diabetic foot (*B*)
Worsening with co-morbidity		Dementia (*A*) of a patient worsened (*B*) after the onset of a pneumonia (*C*)
Complication with co-morbidity		The peripheral artery disease of a patient (*A*) complicates with gangrene of the foot (*B*) after an episode of heart failure (*C*)

A f-HINe diagram can be set up so as to provide two different analytical perspectives, clinical/semeiotic and pathophysiological, related to the two different points of view on the same clinical history. Time plays an important role as well in the evolution of a clinical condition. In a f-HINe diagram the problems are partially ordered: to this end, an implicit right-oriented time abscissa can be associated to the diagram. In case e.g. of two HIs, the agreed rule points out the rightmost one as occurred later [4,5].

4 Methodology

The project involved researchers, directly dealing with clinical activities, from both the Departments of Veterinary Medicine and Animal Productions and of Public Health of the Federico II University of Naples. A first training phase was conducted via a series of meetings (virtual or in presence), with the purpose of showcasing the main features of the HIN approach. A first "teacher version" of a didactic textbook for the deploying of HIN for Medical Sciences was presented to the subjects. They were then asked to figure out as many case studies as possible starting from their actual clinical experiences. The objective was to train them toward a twofold objective: (i) how to translate a real clinical study by means of the HIN features, thus matching the learning objectives and addressing the specific needs related to the human- and animal-related nature of the cases; and (ii) how to design CBL-like exercises based on f-HINe diagrams, to be later delivered to the students. To this regard, a database of exercises to be downloaded for educational use is meant to be hosted in a website specifically designed for the project. The case studies figured out in the first place were then translated into f-HINe diagrams with fHINscene, a tailor-made software learning environment for the design, validation, and evaluation of f-HINe networks for educational purpose, whose features have been introduced and extensively described in [5]. The evaluation of the outputs of the first phase was performed through the submission to the same subjects of a written survey, composed with open-ended questions, delivered and returned via email. The answers were analyzed according to the thematic analysis, in order to extract patterns of meanings [11]. After a careful, repeated reading, the units of meanings - i.e. portions of text that convey a meaning significant for the purposes of the researcher - were identified. The units were then coded with a term or a short expression that conveyed in turn the meaning, and the codes were inductively gathered into themes. The choice of exploring with a method of qualitative research the reaction of the subjects involved, was motivated by the very preliminary phase of the project. Qualitative research can easily produce hypotheses and drafts of systems of meanings, to be then further assessed with quantitative methods. The following three themes emerged:

- "Learning needs" that grouped the topics of "applying theory to practice" and "applying legal rules to prevention";
- "Teaching problems" that grouped the topics of "how to develop critical thinking", "how to develop the ability of identifying the relevant information from the background" and "how to enhance self-directed, problem-based learning";
- "Added value" that grouped the topics of "the power of a synthetic graphic representation" and "the ability to represent patho-physiological correlations".

5 Results

Each researcher was asked to represent the original material by means of a clinical vignette, as this method is widely used to report clinical cases to provide insight into clinical practice and generate hypotheses for innovations in clinical practice, education, and research [12]. The two following examples focus on a human- (Table 2) and a veterinary-based (Table 3) clinical studies, respectively. When necessary, the ICD-10 code [21] of the HI has been reported within square brackets.

Table 2. Human-based case study (Mary)

Mary (fictional name) is a 61 yo woman, non–smoker, affected by nickel allergy, anxiety states, hypertension [*401*], and T2DM [*25000*]. In 2016 she underwent a colonoscopy because of a diverticulosis of the colon [*5621*]. In 2018 a colic-like abdominal pain was treated with antispasmodics and painkillers. Evidence of bilateral renal microlithiasis [*5920*] emerged after abdominal ultrasound. A new episode of kidney failure [*7880*] after some months led to an ER admission, where she was diagnosed with bilateral kidney stones. After the urologic consultation, a medical therapy was prescribed and an extracorporeal lithotripsy (ESWL) was performed, after which a resolution of symptoms was witnessed. A new episode of kidney failure occurred in 2019. Hemato-chemical examinations evidenced modest renal insufficiency [*586*]. A new urological control confirmed the presence of recurrent stones. Medical therapy and antibiotic prophylaxis were conducted, after which new hemato-chemical examinations showed a modest increase of calcemia and creatininemia. Later episodes of kidney failure and of inflammation of the urinary tract [*V1302*] were resolved with self-medication, leading to a partial well-being. An occasional cardiological checkup performed in 2020 with echocardiogram and ultrasound of the neck, evidenced the presence of a parathyroid neoformation of likely adenomatous nature. An endocrinological consultation was conducted. Evidence was found of an increasing dosage for both calcemia [*27542*] and parathormonemia. A following scintigraphy confirmed the diagnosis of Parathyroid Adenoma. Indications for surgical treatment were made, after which an improvement was achieved.

The main GUI of fHINscene contains the work environment where the user can draw the f-HINe diagram, which is divided into two main sections separated by a slidebar, representing the clinical/semeiotic (up) and the pathophysiological (down) levels. The drawable HIs feature some specific characteristics (at the present moment, only related to human medicine): HI code (e.g. ICD-9 coded [13] issue or free term), HI description (e.g. ICD-9 coded or free description), status (e.g. diagnostic hypothesis, etc.). It is anyway possible to handwrite the name of the HI whether it is missing from the ICD list (it is e.g. the case for most veterinary HIs).

The distinction between clinical/semeiotic and pathophysiological levels makes it possible to distinguish between the different perspectives the same case can be analyzed through. On the one hand, the analysis of the sole clinical/semeiotic level (upper side of Fig. 1) provides an immediate, comprehensive vision of the "classic" sequence of clinical activities performed to work out Mary's health issues during the considered time period. As expressed in Table 2, only an occasional check of Mary's chronic conditions - represented by means of the "persistence" evolution - led to acknowledge the parathyroid neoformation that turned out to be the real origin of her whole clinical history; on the other hand, the addition of the pathophysiological level (lower side of Fig. 1) showed what really lied "behind the curtain", making it clear that in a given moment a remarkable increase of PTH/parathormone caused an as high increase of the level of calcemia, which led in turn to the first witnessed episode of bilateral renal microlithiasis. The persistence of these phenomena - as only a treatment of the kidney-related issues was made - caused eventually the adenoma.

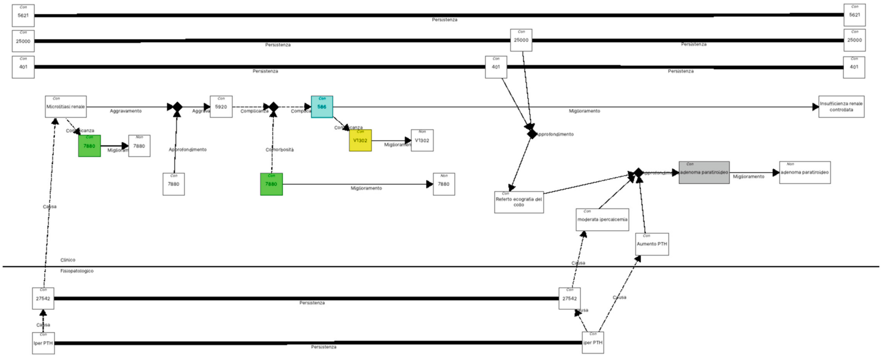


Fig. 1. The f-HINe diagram of the patient "Mary" diagnosed with parathyroid adenoma

Table 3. Veterinary-based case study (Nala) (Source: [14])

Nala, a 10-month-old dog, suffered from a sudden loss of vision and severe dyspnoea [*7860*]. The ocular examination revealed bilateral panuveitis, lens subluxation, secondary glaucoma, and retinal detachment. In addition, the ocular ultrasound showed, in the vitreous body of the right eye, a small doubled-lined foreign body compatible with an intraocular parasite. Radiographs of the thorax revealed an increased opacity with mixed lung pattern (alveolar and bronchial) and thoracic ultrasonography showed several subpleural nodules. The presence of Angiostrongylus vasorum first stage larvae was confirmed with 324 larvae per gram of feces [*5781*], and an antigen test for the parasite (AngioDetect, IDEXX) also yielded a positive result. The severe and irreversible ocular lesions described in this case enhanced the complexity of the clinical picture of canine angiostrongylosis. Infection with the parasite should be included in the list of differential diagnoses for ocular uveitis to avoid potentially serious complications related to a missed or delayed diagnosis.

Also in this case, the clinical/semeiotic level (upper side of Fig. 2) reflects the contents of Table 2, which respond to the traditional way of describing a clinical case, that is reporting the steps performed to find out the origin(s) of the main health issues, as well as the activities to (try to) work them out. Completing it with the pathophysiological level (lower side of Fig. 2) unveils the real role of the pathogenic agent, which stands as the most likely sole origin, although in different moments of time, of the whole set of HIs the dog's clinical history is characterized by.

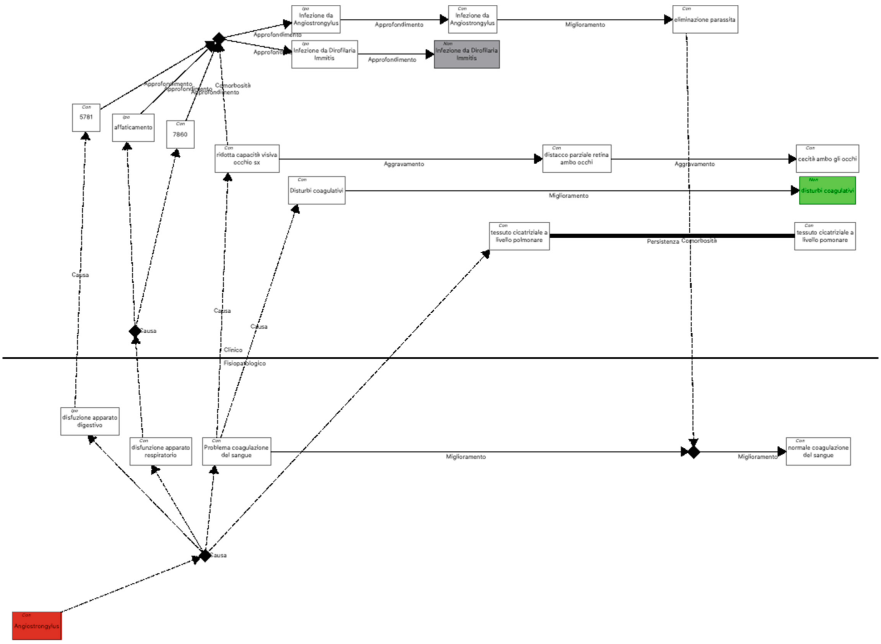


Fig. 2. The f-HINe diagram of the patient "Nala" diagnosed with Angiostrongylus

6 Discussion

According to the "dual process theory" [15] clinical reasoning is based on two different cognitive systems: (i) Intuitive or non-analytic, based on experience and characterized by the rapidity of implementation; (ii) Analytical, through which a decision is reached through a process of rational and conscious analysis, implemented in complex situations, or when there is availability of time. After an initial predominance of the intuitive system, the analytical system takes progressively over, allowing to confirm or reject the hypothesis made in the first place, through careful analysis of data, reports and clinical examinations. This means for human medicine, to deal not only with those diseases included in the list of Essential Levels of Care (LEA, see [22]) but also to e.g. focus, in the near future, on the likely increase of the incidence of rare diseases. On the other hand, for the veterinary medicine this means the possibility to set up a correct clinical-diagnostic approach for as many animal species as possible, and to facilitate the definition and implementation of effective standard operating procedures (SOPs): it is the case, for example, of the increasingly widespread food-borne diseases, which could highlight the presence of links between human and animal health. One of the main innovations introduced by HIN is related to its capacity to allow students to develop the ability to manage these as dynamic phenomena, in their evolution over time, becoming therefore able to anticipate the mutual influences between multiple diseases and co-present conditions.

In particular, the exercises analyzed show the added value of f-HINe, related to its capacity to provide a synthetic graphic representation of a complex clinical case. The diagram that translates the "traditional" written clinical case also enables students to apply in a new way theoretical knowledge to the case itself and encourages the use of inquiry-based learning methods. It is therefore clear how HIN is capable to address in many ways the issues that the didactic methods related to the education of health sciences students are called to deal with. With specific reference to those previously mentioned: (i) the empowered patient can play as a valid support for the health mentor/doctor teacher in order to contribute to an as more realistic as possible design of a network [16]; (ii) the HIN approach allows students to make practice with an instrument that helps them learning how to address complexity of a patient's clinical path [5]; (iii) the Petri Nets-based graphic formalism allows to represent the patient's clinical history distributed over a period of several years. Moreover, the deployment of fHINscene to define, validate and compare f-HINe networks falls within the more general process of refinement of the case-based educational research methods (CBL) coming with it [17].

7 Conclusions and Future Perspectives

In this paper the first results have been described of a project focused on the implementation of HIN as innovative learning technology for professors and researchers of both human and veterinary classes within the "Federico II" University of Naples. In the steps performed so far, the subjects involved have approached the HIN model to work out the ways it is supposed to be integrated within their classes, and several case studies have been analyzed and discussed to elicit the added value related to an effective deployment of HIN

The next steps will focus on the implementation of such learning technology - including the new discovered P-HIN horizon - to the students, in order to gather information as to the ease of use, the immediacy in delivering clinical/organizational outputs, as well as the possibility to pursue common paths of case analysis involving both humans and animals, towards a "One Health" perspective [19, 20].

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