OntoSAMSEI: Interactive ontology engineering for supporting simulation-based training in Medicine

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***Abstract*—Simulation-based training is becoming a central need in medical education. So far, only a few pioneering teachers have developed and documented a pedagogical expertise for setting up training sessions based on simulation, making difficult to share it with less experienced teachers. In this paper, we describe an interactive and incremental ontology modeling approach in order to model such ill-defined domains related to pedagogy. We have built the ONTOSAMSEI ontology for simulation-based medical education domain, and developed a new tool to automatically generate pre-filled forms in order to share the acquired knowledge among domain experts, and collect new information from them to enrich the ontology. We also report on the evaluation by domain experts of the completeness and the accuracy of the ONTOSAMSEI ontology resulting from this incremental methodology supported by a pre-filled graphical user interface.**

***Index Terms*—Semantic Web; Ontology engineering; Knowledge Acquisition; Automatic form generation; Simulation-based training in medicine.**

I. INTRODUCTION

Ontologies have received increasing interest as a mediator between humans and machines as a result of providing the shared conceptual models of experts' domains. Nowadays, many ontologies are made available in the Semantic Web [1], in particular in biology, medicine, and life services, as a result of a collective effort of whole communities.

Ontology construction is a hard and time-consuming task that has been addressed by varied techniques and methodologies, combining text mining and knowledge elicitation from experts. Most of the methods solely focus on well-defined domains such as anatomy, genomics or medical standard terminologies. However, the current approaches are not well adapted for *ill-defined* domains in which formal models do not exist and a little standard documentation is available, thus requiring tremendous effort and subjective judgments from the ontology developers to acquire and maintain the ontology [2]. In this paper, we focus on the construction of specialized ontologies that capture skills of experienced experts in a particular domain with the goal to share them with a larger community of trainee or less experienced experts in the domain. This is the case in particular for domains related to pedagogy because teaching objectives are hard to formalize and teaching methods are difficult to share within a common and standardized referential.

The current trend in the domain of pedagogy is to introduce new methods of teaching skills and not only academic knowledge. In particular, simulation-based medical education has been recognized [3] as a necessity to avoid medical gestures to be applied the first time on patients. Ontology modeling is a good way to design teaching units for learning by simulation but raises difficult issues of knowledge acquisition.

The research problem that we address in this work is how to tackle the challenges raised by ontology engineering of such an ill-defined domain.

Our contribution consists of a methodology with the following steps (as illustrated in Figure 1): (i) *ontology bootstrapping* to initialize the core structure of ONTOSAMSEI by employing a few available documents provided by limited number of experts; (ii) *designing* and *disseminating* an online questionnaire to collect more information from several groups of experts; (iii) *Enhancement* of ONTOSAMSEI to a larger number of simulation-based training sessions using a text mining method on the results of the online questionnaire; (iv) *generating* a tool for automatic pre-filling of web forms guided by the ontology in order to share a common knowledge and enable experts to add new information; (v) *enriching* and *populating* the ontology with the recently added information.

As a result and an illustration of this interactive and incremental methodology for ontology engineering, we have built the ONTOSAMSEI ontology that captures simulation-based medical education.

The paper is organized as follows: Section 2 and Section 3 describe the two main steps of our approach. Section 4

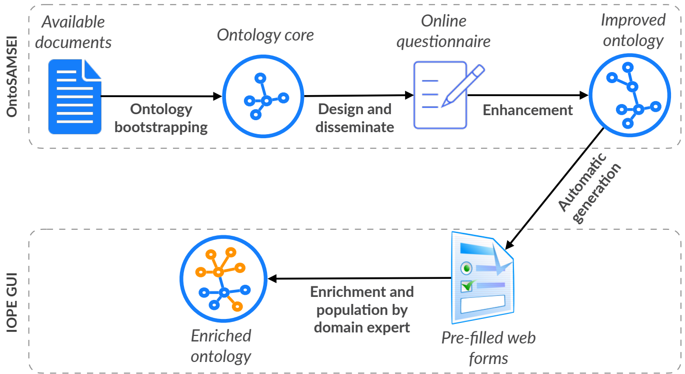

Fig. 1. The five steps of our ontology engineering model ONTOSAMSEI and our ontology update approach IOPE

describes the experimental evaluation that we have conducted to assess the quality of ONTOSAMSEI ontology. Section 5 presents the related work and Section 6 concludes the paper.

II. KNOWLEDGE ACQUISITION FOR ONTOLOGY MODELING

Knowledge acquisition (KA) is the process of extracting, structuring, and organizing domain knowledge from one source, usually human experts for the development of knowledge based systems (expert system) [4]. Knowledge acquisition is possible either through automatic extraction from existing sources or from manual acquisition by contributors. Automatic extraction of data cannot always be achieved specially in ill-defined domains due to the lack of available sources. Manual acquisition allows people to fully use the Semantic Web possibilities but forces all contributors to learn the Semantic Web principles. Learning formal languages such as RFD notations represents an important obstacle to knowledge production especially to non-IT experts.

A more recent and effective approach to knowledge acquisition is a re-use based approach. The knowledge-level hypothesis of Newell [5] states that knowledge should be represented at a level independent from particular implementation-level details. Regarding to this principle and a large impact of web on knowledge acquisition the KA community studied ontology engineering in its modern, pragmatic form: ontologies are not general theories of knowledge, but rather pragmatic and reusable specifications of concepts that represent a consensus view in a particular domain [6]. A formal ontology enables experts to access their data in a structured form which is easily exploitable and extendable. It also decreases learning and knowledge sharing costs.

A. Proposed methodology

For the ontology bootstrapping, we have exploited some reported expertise of a group of pioneer trainers who have documented simulation learning units of various types. As a result we obtained the core structure of our ontology (ONTOSAMSEI) for a few number of simulation sessions like suture, implanting a port, blood transfusion, hygiene and etc. The achieved general structure of ONTOSAMSEI contains the simplest elements to formalize, e.g., targeted audiences, learning objectives, necessary prerequisites, required resources (humans, materials, consumables and simulators), risks incurred during the simulation session and in real situation and evaluation of the prerequisites and objectives.

In the next two steps, We have refined and improved ONTOSAMSEI to a larger number of simulation sessions. For this aim, we have designed an online questionnaire and disseminated it among health trainers in simulation learning, to acquire the most accurate description of various simulation sessions.

We have constructed the online questionnaire from the general achieved structure in step one with several sections that represent several extracted elements to be filled in by the user. These sections expose the targeted audience, the aimed objectives, the prerequisites, the resources required (human, consumable, simulator, material), as well as the evaluation mode of prerequisites and objectives. There is also a section to describe the associated risks.

In order to send the questionnaire with the help of a mediator, we created a directory, listing 1223 health professionals, and provided face-to-face or remote support to help them in answering the questionnaire. We have received 304 responses, representing a 20% return rate nationwide. By using a simple text mining method on the results of the online questionnaire, we group the answers by each simulation session. These answers allowed us to identify 83 different simulation sessions within which 30 were described frequently by the different professionals, and 53 were written only once or partially.

We have improved and refined ONTOSAMSEI by modeling commonalities of the same type of simulation sessions described by different professionals. The resulting ontology is a hierarchy of classes and of properties enriched by *ontological constraints* on the properties and on the classes that convey the constraints that will have to be fulfilled by their future subclasses, subproperties or instances. We added these simulation sessions to the hierarchy of simulation learning unit as a descendent of the principled class.

The ontology editor and visual modeling environment which we used to model ONTOSAMSEI is “TopBraid Composer”. It is a tool for creating and managing domain models and ontologies in the Semantic Web standards RDF, RDFS and OWL. Each class, property, and instance is identified with a URI (Uniform Resource Identifier) and has a label in French and English languages.

B. Results

At the end of step one we had 97 classes, 22 properties, and 38 instances for our first version of ONTOSAMSEI. After step three, i.e., enhancement, the resulting ontology reached to 470 classes, 49 properties, 550 instances, and 700 constraints. Below we denote several extractions of different parts of the resulting ontology.

The ontological constraints that we consider are RDFS constraints and some OWL constraints.

There are 4 types of RDFS constraints:

- **Class specialization constraints** denoted by triples of the form `(C rdfs:subClassOf D)` specify that a class `C` is a subclass of a class `D`, i.e., that every instance `i` of `C` is an instance of `D`: $\forall$ `i ((i rdf:type C)` $\Rightarrow$ `(i rdf:type D))`
- **Property specialization constraints** denoted by triples of the form `(p rdfs:subPropertyOf q)` specify that a property `p` is more specific than a property `q`, i.e.: $\forall$ `i` $\forall$ `j((i p j )` $\Rightarrow$ `(i q j))`
- **Domain constraints for a property** denoted by triples of the form `(p rdfs:domain C)` specify that every subject of a property `p` is an instance of the class `C`, i.e.: $\forall$ `i` $\forall$ `j((i p j )` $\Rightarrow$ `(i rdf:type C))`
- **Range constraints for a property** denoted by triples of the form `(p rdfs:range D)` specify that every object of a property `p` is an instance of the class `D`, i.e.: $\forall$ `i` $\forall$ `j((i p j )` $\Rightarrow$ `(j rdf:type D))`

Figure 2 displays part of the specialization hierarchies of properties and classes resulting from RDFS ontological constraints declared in ONTOSAMSEI. As we observe, there exists properties which specialized several other properties, such as the property `samsei:resources` which is specialized in `samsei:equipmentSupplies`, `samsei:simulatorResources` and `samsei:humanResources`.

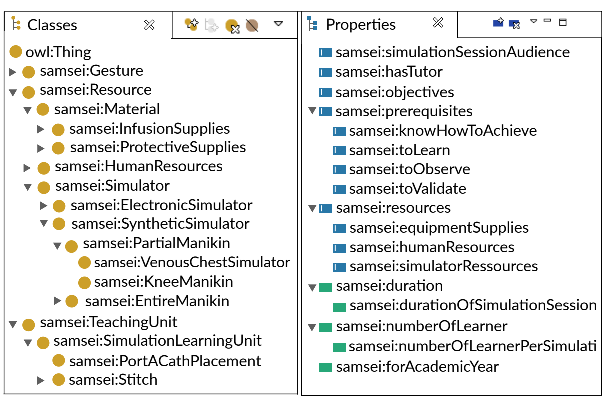

Fig. 2. A part of hierarchy of properties and classes in ONTOSAMSEI.

We consider 3 additional types of constraints that are expressed as OWL restrictions on properties for classes:

- **Cardinality restrictions**, that we will denote by `(p min k D)` $\in$ `Constraints(C)` , specify that every instance `i` instance of the class `C` must be related by the property `p` to at least `k` distinct instances of the class `D`:

$$\forall \mathtt{i}((\mathtt{i\ rdf{:}type\ C}) \Rightarrow \exists o_1, \ldots o_k(\bigwedge_{i,j \in [1..k]} o_i \neq o_j \wedge \bigwedge_{i \in [1..k]} (o_i\ \mathtt{rdf{:}type\ D}) \wedge (\mathtt{i\ p}\ o_i))$$

- **Value restrictions**, that we will denote by `(p value v)` $\in$ `Constraints(C)`, specify that every instance `i` instance of the class `C` must be related by the property `p` to the value `v`:

  $\forall$ `i ( (i rdf:type C)` $\Rightarrow$ `(i p v))`
- **List of values restriction**, that we will denote by `(p rdf:Bag [v1, v2, ..., vn])` $\in$ `Constraints(C)`, specify that every instance `i` instance of the class `C` must be related by the property `p` to a list of values `[v1, v2, ..., vn]`

Figure 3 shows the RDF graphs associated to two constraints declared in the ONTOSAMSEI ontology on the property `samsei:equipmentSupplies` for the class `samsei:PortACathPlacement`, which is a particular type of simulation learning unit that trains students to place a port or a catheter.

The constraint graph in Figure 3(a) expresses that `samsei:sterilecompress` (which is an instance of Bandage material) is declared in the ontology as a mandatory value of the property `samsei:equipmentSupplies`.

The constraint graph depicted in Figure 3(b) expresses that at least one equipment of type `samsei:protectiveSupplies` is mandatory for simulating a placement of a port or a catheter.

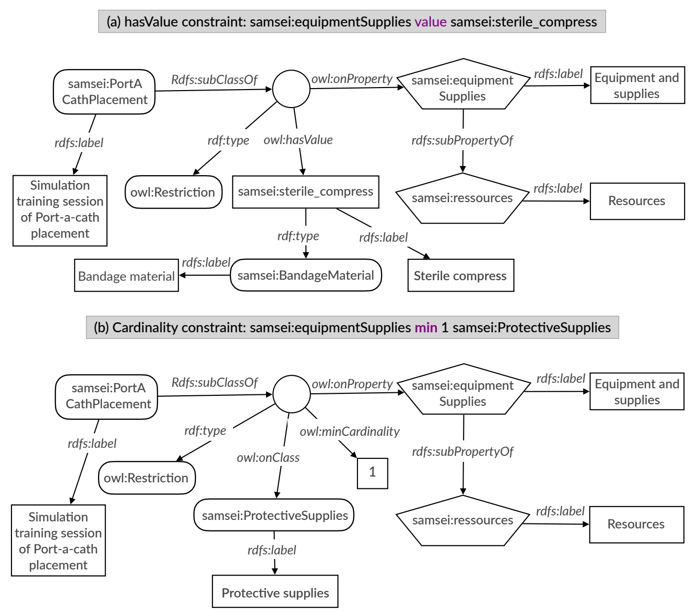

Fig. 3. Two constraint graphs (a) and (b) on the property `equipmentSupplies` for the class `PortACathPlacement`

III. INTERACTIVE ENRICHEMENT OF ONTOSAMSEI

In addition to ONTOSAMSEI ontology modeling, an important part of our work has been to design and to implement an interactive approach for enriching and populating ontologies by involving users in the process. The users that we target are domain experts that are not familiar with ontology formalization and engineering. In particular, they may not know the RDF format and the machinery underlying the different components of an ontology. Many tools have been proposed to generate forms [7] [8] but there is no attempt to generate and pre-fill forms based on ontologies.

Our approach consists in transposing the RDF data and the ontological constraints of a given domain ontology into a graphical user interface (GUI) named IOPE GUI. It functions as a guidance for domain experts to easily explore the ontology and update it through interactive graphical widgets. The input entered by domain experts through the IOPE GUI are transformed into RDF triples that must be verified by an expert in ontology engineering before being added effectively in the domain ontology. Figure 4 is an overview of our interactive IOPE system.

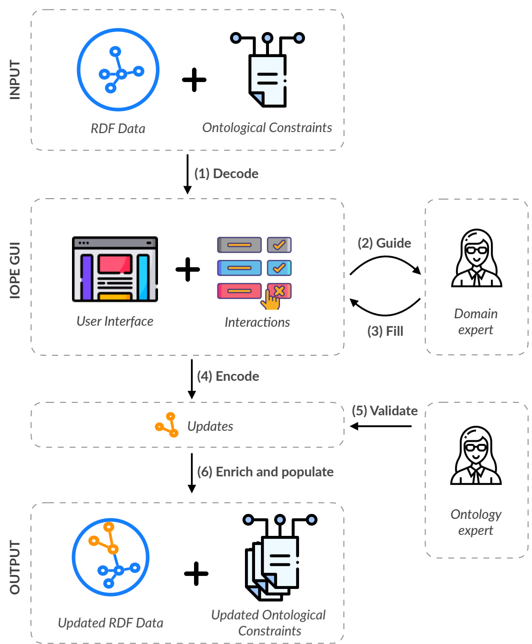

Fig. 4. Overview of IOPE workflow

The IOPE GUI is made of pre-filled Web pages that are automatically generated to reflect the domain ontological constraints. For doing so, we have followed a declarative approach based on a set of *mapping rules* from *ontological constraints graph* to *Web form templates* described using a Web form ontology called IOPE_Web that we have developed by adapting RAUL [9]. The data binding mechanism needed to bind the user input in the pre-filled Web pages to RDF data is performed by a set of *binding rules*. The whole approach and the set of mapping rules and binding rules are given in a companion report [10].

After step five, i.e., Enrichment and population by domain expert, the resulting ontology reached to 472 classes, 49 properties, 590 instances, and 710 constraints.

IV. COMPLETENESS AND ACCURACY OF ONTOSAMSEI ONTOLOGY

The objective of our study is to evaluate the *completeness* and *accuracy* of the ONTOSAMSEI ontology. The users involved in our user study are a subgroup of 32 experts in simulation-based training in Medicine among those who were solicited one year ago through an online questionnaire for bootstrapping the ONTOSAMSEI ontology. They are domain experts but they are not familiar with RDF and OWL. The user study was organized in two steps for each expert. In the first step, the expert logs in the system with her credentials, picks one simulation training session, and begins to observe and update the information in the pre-filled Web pages. Once the expert is done with filling of the Web pages for one training session, she can choose another training session and follow the same process. In the second step, she will be transferred to a survey form to evaluate some qualitative aspects of ONTOSAMSEI ontology and reflect her viewpoint based on her exploration with the IOPE interface.

For a more granular analysis, we group experts in two followings ways:

- *Interaction volume*. We build the following groups of experts in terms of number of interactions they had with the system: "prolific" (experts having more than 6 interactions with IOPE), "active" (experts having between 3 and 6 interactions), and "moderate" (experts with less than 3 interactions). Our experts interacted 5.78 times on average, maximum 14 times, and minimum 3 times.
- *Interaction duration*. We also group experts based on the amount of time they spend with IOPE: "short-time" (less than 2 minutes), "medium-time" (between 2 and 4 minutes), and "long-time" (more than 4 minutes). Our experts spent 2.72 minutes on average, maximum 5.33 minutes , minimum 1.12 minutes.

TABLE I
DISTRIBUTION OF EXPERT GROUPS

	moderate	**active**	**prolific**
Expert population	22.73%	50%	27.27%
	short-time	**medium-time**	**long-time**
Expert population	50%	31.82%	18.18%

Table I shows the distribution of experts in two categories of groups.

TABLE II
MEASURE DEFINITIONS AND CORRESPONDING QUESTIONS ASKED IN THE SURVEY.

Measures	Definition	Question asked in the survey
accuracy [11], [12]	The precision of information based on expert's prior knowledge.	How do you evaluate the accuracy of IOPE's pre-filled information for describing simulation training sessions?
completeness [12]	The retrieval exhaustiveness of the necessary and required information.	How do you evaluate the sufficiency of IOPE's pre-filled information for describing simulation training sessions?

We have measured on a Likert scale in the range 1 to 5 the experts assessment of *accuracy* and *completeness* of the ONTOSAMSEI ontology through its presentation to the experts by IOPE GUI. We do it by asking to the experts the questions in the Table II.

The aggregated results (on the Likert scale from 1 to 5) are shown in the Figure 5.

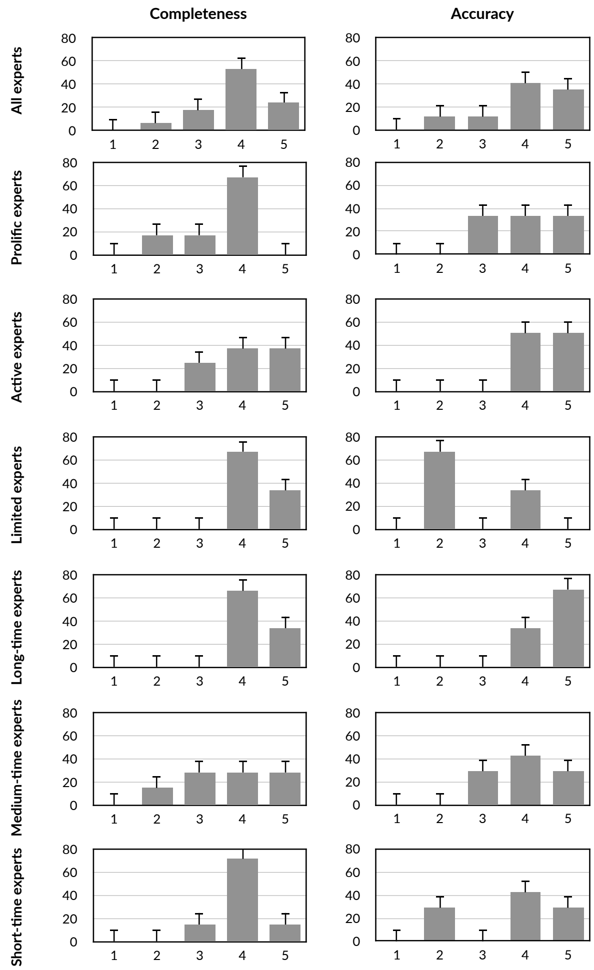

Fig. 5. Completeness and Accuracy metrics results.

Completeness. As depicted in the first column of Figure 5, 76.46% of the participants find ONTOSAMSEI complete enough. However, prolific experts appreciate completeness less than the overall population. By investigating the interactions of this group with the widgets, we found out that they prominently interact with text-boxes for enrichment. Hence this group has presumably more concerns of enriching and populating the ontology to make it more complete. The entire long-time expert group votes positively, which means that they put more time and effort to go into the details of the simulation training sessions and observe their completeness. The votes for medium-time and short-time experts are more scattered.

Accuracy. As depicted in the second column of Figure 5, the majority of the participants are positive on accuracy, while 11.76% are negative. Short-time and moderate experts express more negative votes on accuracy compared to long-time and prolific experts, respectively. This is presumably because less investigations in the former groups did not enable them a precise view of the ontology.

V. RELATED WORK

The literature contains many instances of works addressing multiple ways of representing knowledge such as semantic nets, ontologies, and first order logic [13] [14] [15]. Ontologies have gained immense importance in research as one of the widely re-usable methods to represent and share knowledge in various domains [16] such as software engineering [17], requirement engineering [18], and education [19] in a wide range of applications ranging from explicit representation of domain knowledge to automatic generation of personalized content [20].

Since 1996, in order to represent different aspects of a specific domain, several surveys on ontology engineering methodology have been written [21]–[28].

These methodologies focus on different aspects of ontology engineering [23], [28]:

- Some methodologies are designed to build ontologies from scratch, or promote the reuse of existing ontologies (i.e. NeOn, METHONTOLOGY). KACTUS proposes to build an ontology based on an abstraction process from an initial knowledge base, while SENSUS proposes to automatically generate the ontology's skeleton from a huge ontology.
- Cooperative construction: only the NeOn methodology takes this aspect into account.
- Life cycle proposition: only METHONTOLOGY and On-To-Knowledge methodologies propose a life cycle to identify the set of phases through which the ontology moves during its life.
- Strategies for identifying concepts: (i) top-down approach (i.e. KACTUS); (ii) bottom-up approach (i.e. SENSUS); and (iii) middle-out approach (i.e. METHONTOLOGY, On-To-Knowledge)

In follows, we describe well-known and relevant methodologies. All proposed methods start with the identification of concepts (Scope) and the need for the ontology [29]. The concepts are generally represented as a hierarchy of classes and sub-classes, and different relationships between them. Typically, each of these classes have associated properties and possibly a set of constraints [16]. To determine the scope of the ontology and to extract the main concepts, an ontology design and evaluation method are proposed in [30] which employs a set of natural language questions, called "competency questions". Their major focus, however, is to build the first-order logical model representation of the ontology. The other work by Noy and McGuinness employs a frame-based representation using an iterative approach for building ontologies consisting of several activities which are not required to be sequential [31]. These activities are as follows: (i) determine scope (ii) consider reuse (iii) enumerate terms (iv) define classes (iv) define properties (v) define constraints (vi) create instances. An important conclusion from their work is "there is no single correct ontology for any domain. Ontology design is a creative process and no two ontologies designed by different people would be the same". On-To-

Knowledge [32] is based on analyzing use cases and includes the identification of goals of the knowledge management tools. This methodology is composed of four steps: (i) Kick-off to capture the ontology requirements, identification of the competency questions, and study of the potentially reusable ontologies, (ii) refinement; (ii) evaluation; and (iv) ontology maintenance. NeOn [33] is a scenario based methodology that supports the collaborative aspects of ontology construction. It emphasizes the development of ontology networks as well as the reuse of existing ontological and non-ontological resources to the development of an ontology [28].

In summary, most of the target acquisition sources in the aforementioned methods solely focus on well-defined domains. The current approaches are not effective in understanding the context for ill-defined domains and still require tremendous effort and subjective judgments from the ontology developers to acquire and maintain the ontology [2]. We adapted the NeON and On-To-Knowledge methodology to build the ONTOSAMSEI ontology based on analyzing use cases and the scenario of reuse, fusion, and refinement of resources.

Also, in recent years, very few attempts have been made toward systematically verifying the completeness and accuracy of the ontologies [2]. To the best of our knowledge, no attempts have been made towards interactive and incremental enrichment and refinement of the acquired ontologies.

VI. CONCLUSION

In this paper, we have presented the ONTOSAMSEI, an ontology that formalizes simulation training sessions in simulation-based medical education domain at an ample level of detail to help trainers share a common specification. We developed a new interactive tool named IOPE for enrichment and population of specialized ontologies. We have conducted an extensive experiment for measuring ONTOSAMSEI's completeness and accuracy by the experts.

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