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AN ONTOLOGY TO SUPPORT THE TEACHING OF BASIC MATHEMATICS USING EDUCATIONAL ROBOTICS

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ABSTRACT

Teaching mathematics content in basic education presents some challenges. Many of these challenges have been tackled with the use of information and communication technologies. In this context, educational robotics is gaining space, being increasingly present in school environments. However, there is a shortage of materials to assist teachers in the use of this technology in the classroom. To begin to overcome this problem, this article presents the development of an ontology capable of assisting the teaching and learning of basic mathematics using educational robotics. The ontology called Ontology of Mathematical Content Combined with Educational Robotics (Onto-ENSINARE) was built based on the methodology Ontology Development 101 with the aspects of completeness, consistency, and conciseness. To validate the ontology, SPARQL queries were used to obtain useful answers to basic math teachers.

KEYWORDS: Educational Robotics, Ontology, Mathematics Teaching

UMA ONTOLOGIA PARA APOIAR O ENSINO DE MATEMÁTICA BÁSICA COM USO DE ROBÓTICA EDUCACIONAL

RESUMO

O ensino de conteúdos de matemática na educação básica apresenta alguns desafios. Muitos desses vêm sendo superados com a utilização de tecnologias da informação e comunicação. Nesse contexto, a robótica educacional vem ganhando espaço, estando cada vez mais presente em ambientes escolares. Porém, há escassez de materiais que auxiliem os professores no uso dessa tecnologia em sala de aula. Para começar a suplantar esse problema, neste artigo, apresenta-se o desenvolvimento de uma ontologia capaz de auxiliar o ensino e aprendizagem da disciplina de matemática utilizando robótica educacional. A ontologia denominada Ontologia de Conteúdo de Matemática Combinada com Robótica Educacional (Onto-ENSINARE) foi construída com base na metodologia Ontology Development 101 e validado com relação aos aspectos de completude, consistência e concisão. Para validar a ontologia, foram utilizadas consultas SPARQL para obtenção de respostas úteis aos professores de matemática da educação básica.

PALAVRAS-CHAVE: Robótica Educacional, Ontologia, Ensino de Matemática

1 INTRODUCTION

In the past few years, Information and Communication Technologies (ICTs) have been widely used in the school environment, as an aid for the teaching and learning process. Its usage is observed in several fields such as Science, Technology, Engineering, and Mathematics (STEM) (Earle, 2006; Farias et al., 2021; Lopes et al., 2023).

Although schools adopt different didactic methods for teaching, a substantial number of the students face difficulties in learning new content, such as the concepts that compose the mathematics subject (Santos, 2018). The implementation of robotics as a learning tool for teaching is defined as *educational robotics (ER).* Educational Robotics might be used to leverage the teaching and learning phases, by implementing technologies in classroom time (Santos, 2018). ER is a platform that allows students to not only develop, but to program robots, assisted by a set of particular materials, and specific software developed for such tasks (Reis et al. 2017).

Ribeiro et al. (2023) present a systematic review, which states that educational robotics promotes the abilities associated with computational thinking, problem-solving, creativity, and collaboration, even in an informal education environment (which is the focus of the authors' research). Furthermore, it also carries the potential to increase motivation, self-efficiency, and to present new professional endeavors for students (Queiroz et al., 2023).

The learning process associated with educational robotics is due to its usage in exercises to practically employ theoretical content. ER is yet another tool that enables the absorption of the content more effectively, and it may be carried out in several subjects (Silva, 2017). Nevertheless, its adoption in a classroom time environment requires further in-depth study and commitment by the teachers.

As observed in the literature review about educational robotics, it is possible to observe that several works are applying it through practical exercises, especially within mathematics and physics. However, such works hold as an assumption the prior knowledge about robotics by the teachers, whether in engineering - to the physical assembling of the robots, or programming capabilities. Fewer papers were retrieved regarding the formal development of the teachers, introducing the usage of educational robotics activities to foster mathematics teaching.

In order to properly employ robotics within the classroom environment, not only training courses must be provided, but it is also important to equip teachers with supporting tools. Based on the aforementioned assumptions, we propose the development of an artifact capable of automatically generating complete class plans that support mathematics instructions, by employing educational robotics strategies. Thus, teachers with low expertise in robotics can still derive benefits from its application in the classroom.

To build such a tool, we propose the usage of *ontologies* (Dietz & Hoogervorst, 2006), which are defined as the explicit specification of a description, and a formal representation of concepts and their relationships within a specific domain. Therefore, the main goal of this paper consists of showcasing the development process of an ontology, which will be further used as the foundation of a software artifact, that enables the proper implementation of educational robotics resources to support match teaching.

The proposed ontology shall recommend to the teachers, methods to employ educational robotics within mathematics classes for elementary education. Such employment is presented by the ontology through a class plan, composed of a complete guide for assembling and programming the robot, along with a roadmap of instructions regarding the formative activity – which is the theoretical concept that must be practiced. To develop the ontology, we adopted the Ontology Development 101 methodology (Noy & McGuiness, 2021). The ontology validation was guided by the principles proposed by Gómez-Pérez (2004), i.e., consistency, completeness, and concision.

The further sections of this paper are organized as follows: Section 2 presents the procedures and methods. Section 3 introduces the related works. Section 4 provides a detailed vision of the building process of the ontology. Section 5 thoroughly states the evaluation model for the ontology along with its outcomes. Finally, Section 6 displays the closing thoughts and future works.

2 PROCEDURES AND METHODS

The proposed ontology was developed in Web Ontology Language (OWL), which integrates Description Logic (DL) (Bechhofer et al., 2004). For design and implementation, we used the open-source editor Protégé (desktop), developed and maintained by the University of Stanford (Musen, 2015). We were grounded by the Ontology Development 101 methodology for building ontologies, which comprises an iterative development cycle based on the following phases:

1. Determine the domain and scope of the ontology, which is achieved by answering;
2. Consider reusing existing ontologies, if aligned with the developed one;
3. Enumerate important terms in the ontology, fostering a glossary of terms present in the knowledge base of the ontology, and on its competency questions (with further answers);
4. Define the classes and the class hierarchy, allowing the nesting and granularity definition of the ontology classes. Either adopting a top-down or bottom-up approach;
5. Define the properties of classes, leveraging the relationships among classes (and individuals);
6. Define the facets of the slots (constraints), such as the cardinality, slot-value type (data property), and the domains and ranges;
7. Finally, create instances. Instances are individuals that correspond to a class with distinct property values, equivalent to its properties.

The proposed ontology is hereby defined as *Onto-ENSINARE.* Its domain must encompass distinct mathematics topics pertinent to elementary school, allowing the insertion of educational robotics as a pedagogical tool to support teachers in the teaching process. Subsequent to its design and implementation, through the previously mentioned phases, the ontology undergoes a twofold validation process. Firstly, a group of two experts evaluates each update proposition, then, a second validation is performed by automatic tools that verify the ontology consistency, completeness, and correctness. Those concepts are presented by Gómez-Pérez (2004), and detailed as follows:

1. **Consistency**: Verifies if the ontology's constraints are semantically concise.
2. **Correctness**: Verifies the inclusion of unnecessary or ineffective definitions. It also searches for redundancies on the asserted axioms, if already inferred by distinct axioms.
3. **Completeness**: Verifies if all the propositions presented by the ontology are directly (asserted) or indirectly (inferred) available. Hence, it checks if all definitions are correct.

In this paper, the methodology proposed by Gómez-Pérez (2004) regarding verification and validation was employed. In order to perform inferences, and provide an inferred class hierarchy, we adopted the automated *reasoner Pellet* (Sirin et al., 2007). The correctness and completeness were checked through the Competency Questions (CQ). The Formal CQs were proposed through Protocol and RDF Query Language (SPARQL) queries, as a data-oriented language, there is no inference power on the language itself (Antoniou, 2004).

3 RELATED WORKS

After a literature screening, and to the best of our knowledge, no papers have been found with an identic goal – to provide an ontology regarding educational robotics for mathematics teaching. Accordingly, this section presents a few related works that also uphold the usage of educational robotics as a pedagogical tool, and also papers that address ontologies for describing robotics or mathematics teaching domains.

Almeida Neto (2014) presents a pedagogical tool that supports mathematics classes. The author employs educational robotics activities, such as assembling and programming robots to supplement mathematics classes practically. In this paper, ER has been used as a pedagogical instrument for students. We may highlight that this work does not approach the distinction of the robot parts by their shape, or logical reasoning related to their assembling, which is mandatory when programming a robot.

Rodrigues (2015) proposes a set of mathematical exercises fostered by educational robotics, focusing on rational numbers. The author's goal is to elaborate, implement, and analyze a pedagogical sequence that enables the usage of robotics in mathematics teaching. The paper addresses four distinct exercises, each one containing its introduction, goal, and development. It is possible to observe that throughout the exercise, it lacks guidance on how the teacher must proceed with the students toward the robot programming. Furthermore, this paper provides a short amount of exercises.

Dos Santos et al. (2013) introduce activities exploiting educational robotics on the elementary level within different exact sciences. The authors propose the adoption of the software *Modelix System,* which bears two modes: programming, and simulation mode. The former allows the user to write the code and further visualizes errors, and the latter creates a programming routine, which is simulated in a real environment. Nonetheless, this paper does not provide a manual for assembling or programming the robot.

Araújo (2016) points out the presentation of mathematics classes by implementing robotics, in lower secondary education. The author leverages the transmission of mathematical knowledge by employing educational robotics and its practical implications, such as assembling and programming robots. The main goal of this paper is to facilitate the teaching process by providing the mathematics teacher with a class plan. Nevertheless, this paper provides a limited number of mathematics classes and does not present tools that automatically support the class selection.

Amid papers that employ ontologies, we may highlight Lim et al. (2023), which propose a recommender system for domestic robots, based on the user's emotions, to elicit motivational services for education. Among users, students are also considered. This paper does not hold the teaching or learning processes as the main goal.

In Lmati et al. (2015), the authors introduce the development of a model grounded in two domain ontologies. The main goal is to guide Moroccan students using proper mathematics exercises based on their profiles, abilities, preferences, and motivation. Amidst the results, it has been noticed that alignment of the ontologies enhances the results, however, the manual alignment of ontologies is still an important step towards the mitigation of syntactic ambiguity.

Concepts regarding ontologies and web semantics are utilized by Tzoumpa et al (2016), in order to solve a geometry issue, by measuring the aggregated values to the teaching process and comparing it to traditional teaching methods. The authors also provide a wider scenario of application for the proposed technique within the educational procedures. The researchers argue that the learning and attention processes are significantly improved by visual representation and their relations.

Key papers retrieved in the literature propose the employment of educational robotics to support elementary school teachers. The sole purpose is to assist the teaching process of mathematics topics. Although they foster educational robotics, the related works do not allow the application of substantial topics to all elementary-level math education, or even provide a detailed guide for programming and assembling robots. Further, we were able to retrieve papers that use ontologies for educational robotics and teaching domains. However, to the best of our knowledge, no paper addressed an ontology for the implementation of educational robotics for leveraging mathematics teaching.

Thus, it is possible to highlight the main contribution and unique addition of the proposed work, which is to provide the foundations for the development of such a tool that enables an easier implementation of educational robotics. This tool must support the mathematics teaching process, and it must have a short learning curve, allowing its usage for different expertise levels of teachers in robotics. This paper fulfills its goal by automatically providing a complete class plan, composed of the robotics activities and a detailed manual for assembling and programing the robots.

The manual must represent the quantity and proper utilization practices of the parts, empowering the students to not only assemble the robot but also perform the proposed exercises, using the theoretical mathematics knowledge, taught by the teacher in the theoretical class time.

The class plan is automatically proposed based on an ontology, which is thoroughly presented in the next section.

4 ONTO - ENSINARE: ONTOLOGY FOR TEACHING AND LEARNING SUPPORTED BY EDUCATIONAL ROBOTICS

From a computational perspective, Gruber apud Morais & Ambrósio (2007) define ontology as the classification of a shared conceptualization, which encompasses the presentation of a set of concepts and the relationships among those concepts. The basic structure of an ontology relates to its classes, relationships, functions, axioms, and individuals, detailed as follows:

- The classes are proposed through taxonomies and hold relationships among them (inheritance, equivalence, and disjointness);
- The relationships represent the type of interaction amidst the components of a domain (classes);
- The functions, on the other hand, are represented through attributes and concepts;
- The axioms are supporting tools that enable the modeling of sentences that are always true (truth-makers);
- The instances are the representation of elements or individuals of an ontology.

A viable technique to define the scope of the ontology is to list a set of Competency Questions (CQ). Those competency questions (and proper answers) reveal if the ontology was able to achieve its goals (Gruninger, 1995). The competency questions proposed by Onto-ENSINARE are:

CQ1 – What kind of robot can be used in a specific mathematics exercise? Through this question, given a unique exercise, the ontology must be able to provide a robot (assembling and programming instructions) that supports the practical execution of such an exercise.

QC2 – Which mathematics exercises may be executed employing educational robotics to enhance teaching? As a wider question, the ontology must return a list of exercises that may be performed alongside educational robotics techniques.

QC3 – What mathematics topics can be taught endorsed by educational robotics? This is yet, another general question, once the ontology ought to return the mathematics topics for which there are registered exercises (supported by robots).

QC4 - To which topic does a specific exercise belong? The question points to the ontology's capability to identify the topics that a specific exercise comprises.

QC5 – What parts must be used to assemble a robot in a given exercise? By answering this question, the ontology proves to be capable of returning the expected parts that compose a specific robot, for a given exercise.

QC6 - For a given mathematics topic and robot model, what is the allowed programming to perform a given exercise? The last question seeks to prove the ontology's capability of mapping several programming settings (functionalities) applied to a given model of robot, to support the execution of a given exercise.

The competency questions were retrieved through a set of interviews, performed with 9 different elementary-level mathematics teachers, in the city of Mossoró-RN (Brazil). The interviews were conducted through October 2019. The proposed ontology must be able to answer the competency questions. To present the relevance of the questions regarding the mathematics topics, we used the Cartesian Plane example, however, several other topics could have been the given example.

The interviews also presented the terms used in the further ontology development (glossary of terms). The National Common Curriculum Framework (BNCC) – the Brazilian department responsible for defining public school curriculum, was adopted as another trustful source of terms for the ontology development. The identified terms were: *Parts, Robots, Programming, Topics, Exercises, Levels, and Subtasks*.

Moreover, we defined the ontology class hierarchy. The class hierarchy is represented by a taxonomy of classes (class-subclass), which undergoes the principle of inheritance (Gómez-Pérez, 2004), which is showcased in Figure 01. The first level classes are inherited from the native class owl:Thing, and those are: *Class, ProgrammingBlock, Subtasks, Exercise, Parts, Robots, and Subject.* Overall, 7 primitive classes were introduced, and 377 (three hundred and seventy-seven) subclasses.

In Figure 01, we may observe that the classes represent the mathematics contents aligned with its teaching supported by educational robotics. The ontology is termed by Onto-ENSINARE, and its structure is thoroughly presented as follows. The class *Class* represents the information that compose the mathematics classes. The class *ProgrammingBlock* represents the EV3 programming blocks, which are presented by the *Lego* kit programming language (Lego Mindstorms EV3, 2020). The class *SubTasks* represents the information on which tasks may be performed by employing the programming blocks. The class *Exercise* represents the information regarding the exercise related to mathematics contents, supported by robotics. The class *Parts* represents the mandatory parts to assemble the robot. The class *Robot* represents the robots that may be assembled in this ontology, by its parts. Finally, the class *Subject* represents the contents of mathematics mapped by this ontology.

The next step in our design cycle is to define the ontology's *Data Properties*. Overall, 11 properties have been presented. The structure follows the *triple* architecture, hence, its *object* (pointed out as the *domain* of the property), its *predicate* (the data property itself), and its *subject* (referred to as *range*), are further presented. The domain of a property refers to what class it belongs to, whereas its range, defines what its subject must be, which for a data property, ought to be a data type, e.g., *string*, *boolean*, *int*.

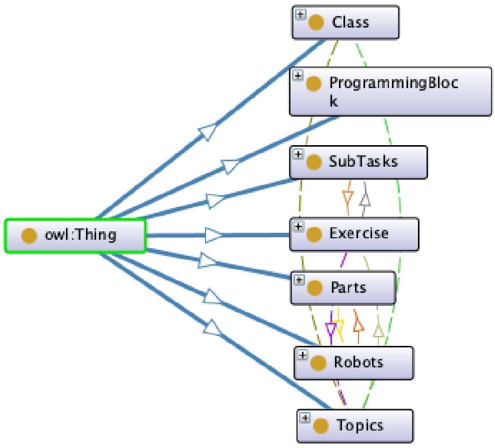

Figure 01 – Ontology structure

Figure 02 presents the final data property hierarchy. The properties *belongsToSubject*, *hasHistory*, *hasLevel*, hold at their domain the class *Topics,* and the range points to an xsd:*string.* The properties *hasTimeSpan*, *hasGoal*, *hasPedagogicalAid*, and *hasReference*, are connected to a domain of class *Class* and are associated with a range of xsd*:string*. Moreover, the data property has *Assembling* relates with the domain of class *Parts,* and further associates to the range of xsd:*string* as well. Finally, the property *hasQuantity* is attached to the domain of class *Programming* and *Parts,* and links to the range of *integer*.

Figure 02 - *Data property* hierarchy

Additionally, we defined the *Object Properties,* which, based on the concept of *triples,* are defined by the *object* (referred to as the *domain)*, the *predicate* (the object property itself), and the *subject, (which is its range).* For the *Object Properties,* the domains are still the class that is characterized (the object), however, the *range* of an object property is another class. For instance, the property *hasExercise* associates the class *Topics* to the class *Exercise,* whereas the property isExerciseOf, connects (inversely) the class *Exercise* to *Topics.* Board 01 presents the properties, their domains, ranges, and descriptions.

Board 01 – ONTO-ENSINARE object properties

Property	**Domain**	**Range**	**Description**

hasExercise	*Topics*	*Exercise*	*This property indicates that an exercise is related to a topic.*
hasProgramming Block	*ProgrammingBLock, Parts, Robots, and SubTasks*	*ProgrammingBlock*	*This property allows to relate a programming block to parts, robots, and subtasks.*
hasTopic	*Class*	*Topics*	*This property implies that a topic is related to a class.*
hasPart	*Robots*	*Parts*	*This property relates a part to a robot.*
hasSubTask	*Exercises*	*SubTasks*	*This property relates a subtask to an exercise.*
Uses	*Exercises, SubTasks*	*Robots, SubTasks*	*This property enables the relation between a subtask to an exercise and subtask.*
isExerciseOf	*Exercises*	*Topics*	*This property is the inverse of hasExercise, and implies that an exercise belongs to a topic.*
isProgrammingBlockOf	*ProgrammingBlock*	*ProbrammingBLock, Parts, Robots, and SubTasks*	*This property is the inverse of hasProgrammingBlock.*
isTopic	*Topic*	*Class*	*This property is the inverse of hasTopic, indicating that a topic belongs to a class.*
isPartOf	*Parts*	*Robots*	*This property is the inverse of hasPart, and it indicates the relationship where a part belongs to a robot.*
isSubTaskOf	*SubTasks*	*Exercise*	*This property is the inverse of hasSubTask, which implies that subtasks belong to an exercise.*
IsUsed	*Robots, SubTasks*	*Exercise, SubTasks*	*This property is the inverse of uses, and it relates robots and subtasks to exercise.*

5 ONTOLOGY VALIDATION

Validation is the process of assessing the quality of an ontology (Vrandečić, 2009). To validate onto-ENSINARE, we employed the criteria of verification, validation, and evaluation proposed by Gómez-Pérez (2004). As mentioned in Section 2, and as the first step for validation, to verify the proposed ontology, we relied on the automatic reasoner *Pellet*, supported by the development tool *Protégé*[1]*,* as a plugin.

Successive to its execution, we were able to observe that the inferred class hierarchy was equivalent to the asserted class hierarchy. Pointing that the ontology is consistent, and there are no errors in its definition that would result in unwanted behavior. Figure 03 showcases the asserted and inferred class hierarchy.

Figure 03 – (a) Asserted class hierarchy; (b) Inferred class hierarchy

Furthermore, the next stage of validation is due to the verification of *object properties,* which similarly to the *data properties,* remained the same for asserted and inferred hierarchies. After executing the *reasoner*, we may verify such a premise with no unexpected behavior. Figure 04 illustrates the asserted and inferred hierarchy for data properties and object properties.

Finally, the last stage of validation proposes the verification of the ontology through the competency questions (Gruninger, 1995). The competency questions allow the assessment regarding the ontology completeness and correctness. For this step, the informal competency questions must be translated to formal competency questions, which for this ontology, we are performing the querying process supported by SPARQL.

[1] https://protege.stanford.edu

Figure 04 – a) Object Properties asserted hierarchy; b) Object Properties inferred hierarchy; c) Data Properties asserted hierarchy; d) Data Properties inferred hierarchy

The first informal competency question is 'What kind of robot can be used in a specific mathematics exercise?'. Figure 05 represents the SPARQL query that searches for the robot classes that are related to classes of exercises. Based on lines 8 and 10 of the presented SPARQL code, we ought to retrieve the classes representing the topics in the class mathematics. In lines 11 and 13, we searched for which exercises are related to the topics brought by the first part of the query, associated with the class robots. Finally, the code in lines 14 and 15, based on the retrieved code so far, the classes are indeed confirmed as robots, once those classes are subclasses of the main class educator robot (standard model from *Lego Mindstorms EV3 kit*).

```
1. PREFIX owl: <http://www.w3.org/2002/07/owl#>
2. PREFIX rdf: <http://www.w3.org/1999/02/22-rdf-syntax-ns#>
3. PREFIX rdfs: <http://www.w3.org/2000/01/rdf-schema#>
4. PREFIX xsd: <http://www.w3.org/2001/XMLSchema#>
5. PREFIX onto: <http://www.semanticweb.org/les-10/ontologies/2019/8/untitled-ontology-12#>
6. SELECT  ?Content ?Topics ?Subject ?SpecificExercise ?Robots
7. WHERE {
8.          ?Content rdfs:subClassOf ?Topics .
9.          ?Topics rdfs:subClassOf ?Subject .
11.         ?Subject rdfs:subClassOf onto: Topics .
11.         ?Content rdfs:subClassOf ?Exercise
12.         ?exercise owl:someValuesFrom ?SpecificExercise .
13.         ?SpecificExercise rdfs:subClassOf ?Robots .
14.         ?Robots owl:someValuesFrom ?Robots .
15.         ?Robots rdfs:subClassOf onto:Robots .
16. }
```

Figure 05: First formal competency question (SPARQL query)

Figure 06 showcases the outputs from the previous query, focusing on the content, topic, subject, exercises, and the robots that are able to support those. In the prior version of the ontology, we only developed the educator robot. However, this robot can support the execution of several basic mathematics exercises. Moreover, it features a user-friendly assembly, hence, it may be widely used as a pedagogical aid.

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conteudo	Assuntos	Disciplina	AtividadeEspecifica	Robos
GraficosDeBarras	ProbabilidadeeEstatisca	Matematica	AtividadeDeGraficosDeBarras	RoboEducador
LeituraeInterpretacao9	ProbabilidadeeEstatisca	Matematica	AtividadeDeLeituraDeInterpretacao	RoboEducador
PlantasBaixas	GrandezaseMedidas	Matematica	AtividadeDePlantaBaixa	RoboEducador
EquacaoLinear1grau	Algebra	Matematica	AtividadeEquaçãolinearde1graunoplanoCa	RoboEducador
Angulos6	GrandezaseMedidas	Matematica	AtividadeDeAngulos	RoboEducador
ColetadeDados6	ProbabilidadeeEstatisca	Matematica	AtividadeDeColetaDeDados	RoboEducador
Poligonos	Geometria	Matematica	AtividadeDePoligonos	RoboEducador
CalculoProbabilidade6	ProbabilidadeeEstatisca	Matematica	AtividadeDeCalculoDeProbabilidade	RoboEducador
CongruenciaDeTriangulo	Geometria	Matematica	AtividadeDeCongruenciaeTriangulo	RoboEducador
PerimetrodeUmQuadrado6	GrandezaseMedidas	Matematica	AtividadeDePerimetroDeQuadrado	RoboEducador
Triangulo	Geometria	Matematica	AtividadeTriangulo	RoboEducador
RelacaoMetricasnoTrianguloRetangulo9	Geometria	Matematica	AtividadeTrianguloRetangulo	RoboEducador
EstatisticaMedia7	ProbabilidadeeEstatisca	Matematica	AtividadeDeEstaticaeMedia	RoboEducador
AnguloInternoExterno	Geometria	Matematica	AtividadeAnguloInternoExterno	RoboEducador

Figure 06: Formal competency question 1 SPARQL query outcome[2]

The second SPARQL query corresponds to the formal competency question version of the informal CQ '– Which mathematics exercises may be executed employing educational robotics to enhance teaching?'. Figure 07 presents the formal competency question version, through the query that retrieves the exercises that relate to robots. In Figure 07, lines 8 and 9 retrieve the classes that represent the exercises related to robots. Whereas lines 10 and 11 endorses the retrieval of classes that are indeed robots, once they are related to the class educator robot. The lower portion of Figure 07 showcases the obtained outcome, corresponding the exercises to its robots.

```
1. PREFIX owl: <http://www.w3.org/2002/07/owl#>
2. PREFIX rdf: <http://www.w3.org/1999/02/22-rdf-syntax-ns#>
3. PREFIX rdfs: <http://www.w3.org/2000/01/rdf-schema#>
4. PREFIX xsd: <http://www.w3.org/2001/XMLSchema#>
5. PREFIX onto: <http://www.semanticweb.org/les-10/ontologies/2019/8/untitled-ontology-12#>
6. SELECT  ?Exercise ?SpecificExercise ?Robots
7. WHERE {
8.          ?Exercise owl:someValuesFrom ?SpecificActivity .
9.            ?SpecificActivity rdfs:subClassOf ?robot .
10.           ?robot owl:someValuesFrom ?Robots .
11.           ?rdfs:subClassOf onto:Robots
12. }
```

AtividadeEspecifica	Robos
AtividadeDeGraficosDeBarras	RoboEducador
AtividadeDeLeituraDeInterpretacao	RoboEducador
AtividadeDePlantaBaixa	RoboEducador
AtividadeEquaçãolinearde1graunoplanoCartesiano	RoboEducador
AtividadeDeAngulos	RoboEducador
AtividadeDeColetaDeDados	RoboEducador
AtividadeDePoligonos	RoboEducador
AtividadeDeCalculoDeProbabilidade	RoboEducador
AtividadeDeCongruenciaeTriangulo	RoboEducador
AtividadeDePerimetroDeQuadrado	RoboEducador
AtividadeTriangulo	RoboEducador
AtividadeTrianguloRetangulo	RoboEducador
AtividadeDeEstaticaeMedia	RoboEducador
AtividadeAnguloInternoExterno	RoboEducador

Figure 07: SPARQL query representing the formal competency question 2 and outcome

The third formal CQ is based on the question 'What mathematics topics can be taught endorsed by educational robotics?'. Figure 08 proposes the formal CQ founded on the SPARQL query that searches for the subject related to the class content. Lines 8 to 10, retrieve the classes representing content that are topics of mathematics. The code present in lines 10 and 11 recovers the classes that are indeed robots, once they are related to the class educator robot. Similarly, the lower portion of Figure 08 presents the query outcome, highlighting the subject, content, and what robot can be used to support this content teaching.

[2] Translation note: The ontology was developed in Portuguese, henceforth, all the hereby presented results are in Portuguese. The previous figures provide an informal glimpse of the English translation, in a specific translation.

```
PREFIX owl: <http://www.w3.org/2002/07/owl#>
PREFIX rdf: <http://www.w3.org/1999/02/22-rdf-syntax-ns#>
PREFIX rdfs: <http://www.w3.org/2000/01/rdf-schema#>
PREFIX xsd: <http://www.w3.org/2001/XMLSchema#>
PREFIX onto: <http://www.semanticweb.org/les-10/ontologies/2019/8/untitled-ontology-12#>
SELECT  ?Subject ?Contet ?Robots
WHERE {
        ?content rdfs:subClassOf ?Subject .
        ?Subject rdfs:subClassOf onto:Subject .
        ?robot owl:someValuesFrom ?robots .
        ?Robots rdfs:subClassOf onto:Robots .
}
```

Disciplina	conteudo	Robos
Matematica	Geometria	RoboEducador
Matematica	GrandezaseMedidas	RoboEducador
Matematica	ProbabilidadeeEstatisca	RoboEducador
Matematica	Numeros	RoboEducador
Matematica	Algebra	RoboEducador
Matematica	Geometria	RoboEducador
Matematica	GrandezaseMedidas	RoboEducador
Matematica	ProbabilidadeeEstatisca	RoboEducador
Matematica	Numeros	RoboEducador
Matematica	Algebra	RoboEducador
Matematica	Geometria	RoboEducador
Matematica	GrandezaseMedidas	RoboEducador
Matematica	ProbabilidadeeEstatisca	RoboEducador
Matematica	Numeros	RoboEducador

Figure 08: SPARQL query representing the formal competency question 3 and outcome

The fourth query represents the informal question ‘To which topic does a specific exercise belong?’. Figure 09 presents the SPARQL query assigned to recover all the exercises related to content. The code present in lines 8 and 9 aimed towards the contents. Moreover, lines 10 and 11 ensure that the retrieved classes are related to exercises.

```
1. PREFIX owl: <http://www.w3.org/2002/07/owl#>
2. PREFIX rdf: <http://www.w3.org/1999/02/22-rdf-syntax-ns#>
3. PREFIX rdfs: <http://www.w3.org/2000/01/rdf-schema#>
4. PREFIX xsd: <http://www.w3.org/2001/XMLSchema#>
5. PREFIX onto: <http://www.semanticweb.org/les-10/ontologies/2019/8/untitled-ontology-12#>
6. SELECT  ?Subject ?Topics ?Content ?SpecificExercise
7. WHERE {
8.         ?Content rdfs:subClassOf ?Topics .
9.         ?Topics rdfs:subClassOf ?Subject.
10.        ?Contet rdfs:subClassOf ?exercise .
11.        ?exercise owl:someValuesFrom ?SpecificExercise .
12. }
```

Figure 09: SPARQL query representing the formal competency question 4

Figure 10 displays the obtained outcome, presenting the subject, topic, content, and exercises that may be taught with mathematics content.

Disciplina	Assuntos	Conteudo	AtividadeEspecifica
Matematica	Numeros	Porcentagens8	AtividadeDePorcentagem8
Matematica	Geometria	AnguloInternoExterno	AtividadeAnguloInternoExterno
Matematica	Geometria	Planocartesiano	AtividadePlanoCartesiano
Matematica	ProbabilidadeeEstatisca	EstatisticaMedia7	AtividadeDeEstaticaeMedia
Matematica	ProbabilidadeeEstatisca	CalculoProbabilidade6	AtividadeDeCalculoDeProbabilidade
Matematica	Numeros	NumerosInteiros	AtividadeNumerosInteiros
Matematica	ProbabilidadeeEstatisca	ColetadeDados6	AtividadeDeColetaDeDados
Matematica	Algebra	EquacaoLinear1grau	AtividadeEquaçãolinearde1graunoplanoCartesiano
Matematica	Numeros	SistemadeNumeracaoDecimal	AtividadeSistemadeNumeracaoDecimal
Matematica	Numeros	MultiplosDivisoresNN7	AtividadeDeMultiplosEDivisores
Matematica	ProbabilidadeeEstatisca	LeituraeInterpretacao9	AtividadeDeLeituraDeInterpretacao
Matematica	GrandezaseMedidas	PerimetrodeUmQuadrado6	AtividadeDePerimetroDeQuadrado
Matematica	GrandezaseMedidas	PlantasBaixas	AtividadeDePlantaBaixa
Matematica	ProbabilidadeeEstatisca	GraficosSetores7	AtividadeDeGraficoseSetores

Figure 10: Formal competency 4 SPARQL query outcome

The fifth query represents the informal question ‘What parts must be used to assemble a robot in a given exercise?’. Figure 11 exhibits the SPARQL query structure assigned to reach the class robot. The code in lines 8 to 14, retrieves the mandatory parts for the assembling of the *EducatorRobot*. Further, the code in line 15 ensures that the educator robot will receive the correct quantity of parts, and finally, line 16 obtains the description for each robot part.

```
1. PREFIX owl: <http://www.w3.org/2002/07/owl#>
2. PREFIX rdf: <http://www.w3.org/1999/02/22-rdf-syntax-ns#>
3. PREFIX rdfs: <http://www.w3.org/2000/01/rdf-schema#>
4. PREFIX xsd: <http://www.w3.org/2001/XMLSchema#>
5. PREFIX onto: <http://www.semanticweb.org/les-10/ontologies/2019/8/untitled-ontology-12#>
6. SELECT  ?parts ?Description ?quantity
7. WHERE {
8.         onto:EudcatorRobot owl:equivalentClass/owl:intersectionOf ?list .
9.         ?list rdf:rest */rdf:first ?element .
10.        ?element owl:someValuesFrom ?assembly .
11.        ?assembly owl:intersectionOf ?partsList1 .
11.        ?assembly owl:intersectionOf ?partsList1 .
12.        ?assembly owl:intersectionOf ?partsList2 .
13.        ?partsList1 rdf:rest*/rdf:first ?parts .
14.        ?partsList2 rdf:rest*/rdf:first ?part2 .
15.        ?part2 owl:hasValue ?quantity .
16.        ?parts rdfs:comment ?Description .
17.        FILTER NOT EXISTS {?parts owl:onProperty onto:hasQuantity}}
```

Figure 11: SPARQL query representing the formal competency question 5

Figure 12 presents the query outcome, highlighting the parts, their description, and the quantity of each part present in the robot assembly. Although the ontology is able to return a complete detailed description for each part, for a matter of space, the console only presents a part of them, in Figure 12, we are able to visualize the beginning of each part description.

pecas	Descricao	quantidade
Bloco_EV3	"Peça Bloco Ev3 Descrição: BLOCO EV3: o bloco programável controla	"1"^^<http://www.w3.org/2001/XMLSchema#integer>
Bloco_conversor_2_Cinza	"Peça Bloco conversor de 2 Descrição: Esta parte é composta por dois	"2"^^<http://www.w3.org/2001/XMLSchema#integer>
Bloco_conversor_duplo_3_Preto	"Peça Bloco conversor duplo de 3 Descrição: Esta peça muito útil para	"2"^^<http://www.w3.org/2001/XMLSchema#integer>
Cabo_25	"Peça: Cabo 25, 35 e 50 Descrição: Utilizando os cabos conectores pre	"2"^^<http://www.w3.org/2001/XMLSchema#integer>
Eixo_3_cinza	"Peça Eixo de 3 Descrição: Os eixos são muitos importantes, pois além	"2"^^<http://www.w3.org/2001/XMLSchema#integer>
Eixo_4_preto	"Peça Eixo de 4 Descrição: Os eixos são muitos importantes, pois além	"2"^^<http://www.w3.org/2001/XMLSchema#integer>
Eixo_com_limitador_4_Cinza	"Peça: Eixo com limitidador de 4 Descrição: Possui 4 dentes para enca	"2"^^<http://www.w3.org/2001/XMLSchema#integer>
Eixo_com_limitador_8_Cinza	"Peça: Eixo com limitador 8 Descrição: Possui 8 dentes para encaixes	"2"^^<http://www.w3.org/2001/XMLSchema#integer>
Esfera_de_aco	"Peça esfera de aço. Descrição: Esta bola forma uma espécie de roda e	"1"^^<http://www.w3.org/2001/XMLSchema#integer>
Estrutura_5x11	"Peça Estrutura 5x11 Descrição: A estrutura de 5x11 é semelhante a	"1"^^<http://www.w3.org/2001/XMLSchema#integer>
Estrutura_5x7	"Peça: Estrutura de 5x7 Descrição: Uso para fixação dos motores, de f	"1"^^<http://www.w3.org/2001/XMLSchema#integer>
Indicador_branco	"Peça Indicador Descrição: Esta peça permite a conexão a um eixo, e	"2"^^<http://www.w3.org/2001/XMLSchema#integer>
Motor_Grande	"Peça Motor Grande Descrição: O Motor Grande é um potente motor "	"2"^^<http://www.w3.org/2001/XMLSchema#integer>
Pino_Conector_Com_Friccao_3_modulo_azul	"Peça Pino Conector com Fricção de 3 módulo azul Descrição: Utilizar	"7"^^<http://www.w3.org/2001/XMLSchema#integer>

Figure 12: Formal competency 5 SPARQL query outcome

Finally, the sixth and last query, corresponds to the informal question 'For a given mathematics topic and robot model, what is the allowed programming to perform a given exercise?'. Figure 13 represents the SPARQL query structure, in which, we searched for the allowed programming related to a specific content and robot. The code of lines 8 and 9 presents the contents related to the subject of mathematics. Code in lines 10 and 11, retrieves what contents are related to a specific exercise. Furthermore, the code in lines 13 and 14 explored the robots and specific programming for each exercise. At last, line 15 reaches the classes that are indeed robots, once they are related to the educator robot.

```
1. PREFIX owl: <http://www.w3.org/2002/07/owl#>
2. PREFIX rdf: <http://www.w3.org/1999/02/22-rdf-syntax-ns#>
3. PREFIX rdfs: <http://www.w3.org/2000/01/rdf-schema#>
4. PREFIX xsd: <http://www.w3.org/2001/XMLSchema#>
5. PREFIX onto: <http://www.semanticweb.org/les-10/ontologies/2019/8/untitled-ontology-12#>
6. SELECT  ?content ?SpecificExercise ?Robots ?Programming
7. WHERE {
8.          ?subclassClass owl:someValuesFrom ?content .
9.           ?content rdfs: subClassOf * onto:Topics .
10.          ?content rdfs:subClassOf ?exercise .
11.          ?exercise owl:someValuesFrom ?specificActivity .
12.          ?SpecificExercise rdfs:subClassOf ?robot .
13.          robot owl:someValuesFrom ?Programming .
14.          programming owl:someValuesFrom ?Robots
15.          ?Robots rdfs:subClassOf onto:Robots .
16.          FILTER NOT EXISTS {?Programming rdfs:subclassOf * onto:Robots}
17. }
```

Figure 13: SPARQL query representing the formal competency question 6

Figure 14 portrays the outcome, focusing on the content, specific exercises, robots, and programming for a given mathematics exercise. According to the SPARQL query, the ontology was able to answer the 6 proposed competency questions. Therefore, the ontology met and exceeded the anticipated requirements of correctness and completeness. The ontology is validated based on the proposed principles for assessment, which implies its implementation in a tool responsible for providing class plans that relate to educational robotics support, as a pedagogical appliance for teaching entry-level mathematics.

conteudo	AtividadeEspecifica	Robos	Programacao
AnguloInternoExterno	AtividadeAnguloInternoExterno	RoboEducador	TarefaDeStart
AnguloInternoExterno	AtividadeAnguloInternoExterno	RoboEducador	TarefaDeVirada and (TemQuantidade value 6)
AnguloInternoExterno	AtividadeAnguloInternoExterno	RoboEducador	TarefaDeLinhaReta and (TemQuantidade value 7)
Planocartesiano	AtividadePlanoCartesiano	RoboEducador	TarefaDeStart
Planocartesiano	AtividadePlanoCartesiano	RoboEducador	TarefaDeLinhaReta and (TemQuantidade value 4)
Planocartesiano	AtividadePlanoCartesiano	RoboEducador	TarefaDeVirada and (TemQuantidade value 3)
Planocartesiano	AtividadePlanoCartesiano	RoboEducador	TarefaDeStart
Planocartesiano	AtividadePlanoCartesiano	RoboEducador	TarefaDeLinhaReta and (TemQuantidade value 4)
Planocartesiano	AtividadePlanoCartesiano	RoboEducador	TarefaDeVirada and (TemQuantidade value 3)
Triangulo	AtividadeTriangulo	RoboEducador	TarefaDeStart
Triangulo	AtividadeTriangulo	RoboEducador	TarefaDeVirada and (TemQuantidade value 2)
Triangulo	AtividadeTriangulo	RoboEducador	TarefaDeLinhaReta and (TemQuantidade value 3)
CongruenciaDeTriangulo	AtividadeDeCongruenciaeTriangulo	RoboEducador	TarefaDeVirada and (TemQuantidade value 4)
CongruenciaDeTriangulo	AtividadeDeCongruenciaeTriangulo	RoboEducador	TarefaDeLinhaReta and (TemQuantidade value 5)

Figure 14: Formal competency 6 SPARQL query outcome

6 CONCLUSION

This paper presented the complete development process of Onto-ENSINARE, which was first proposed as an instrument design purpose, which would allow the further implementation of a tool that supports elementary mathematics teaching by educational robotics. The development of such ontology was solely guided by the *Ontology Development 101* methodology. It is capable of providing a clear description of how to perform mathematics exercises supported by educational robotics. Consequently, a set of services that leverages the usage of educational robotics within the classroom environment is provided. The ontology is fully functional, and it carries an expansion possibility, allowing the implementation of different subjects.

Once the ontology was developed, three aspects were evaluated, i.e., consistency, completeness, and concision, which were fulfilled, with no constraints, execution errors, or redundancy. Those results ground the assumption of the further implementation of this ontology as the foundation for the development of a recommender system, which enables the recommendation of class plans along with the description of exercises supported by educational robotics for a given content searched by the teacher. As future works, we propose the implementation of the presented ontology in a web recommender system, able to provide services in a recommendation environment.

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