EVALUATION AND EVOLUTION OF NAONTO- A PROFILE ONTOLOGY OF NATIVE AMERICAN DIABETES PATIENTS

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ABSTRACT

Diabetes is one of the deadliest diseases worldwide. Its prevalence is highest amongst the American Indian (AI) community. The existing ontology-based self-management tools for native Americans lack comprehensiveness and are not well evaluated. Hence in this paper, we focus on creating and evaluating a profile ontology for the American Indian diabetic patients which can lead to the creation of personalized self-management tools so the community can better manage this disease. Our approach is composed of creating a profile ontology for the American Indian community by acquiring their cultural, geographical, food intake and related information, and evaluating the correctness of the created ontology with regards to the OQuaRE evaluation framework. The quality model is divided into multiple dimensions each of which is further divided to create a series of quality metrics for evaluation. In addition, we also evaluate the performance of the Ontology using various available tools like Oops, Onto Debugger.

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I will like to thank my research advisor Dr. Jen Li, my family and Shadi Alian for trusting in me and supporting me through my ups and downs in order to achieve my goal.

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INTRODUCTION

Diabetes is one of the most serious conditions affecting almost 422 million people worldwide and more than 30 million people in United States itself. Diabetes causes the blood sugar levels go higher than usual which could lead to blindness, limb amputation or other fatal conditions like kidney failure as well. It occurs when the body is either unable to produce or properly utilize the produced insulin in the body. The most common types of diabetes are Type 1 and Type 2 along with other types like Prediabetes and Gestational Diabetes.

Native Americans that includes American Indians and Alaskan Natives have a greater chance of being affected by diabetes than any other racial group in the United States of America. According to the National Diabetes Statistics Report, prevalence of diabetes in the US was recorded highest among the American Indians/Alaska Natives (AI/AN) at 14.7% of all the US Population by the end of year 2018 [1]. As per the report “Traditions and Diabetes Prevention”, the lifestyle changes had a negative impact on the Native American population [2]. They have a higher rate of obesity and a higher rate of diabetes due to their dietary patterns which includes low intake of fibers, higher dietary fat along with less energy expenditure. The AI/AN community suffer from diabetes mostly due to their genetics, as well as due to environmental and behavioral issues. Some additional contributing factors include a sedentary lifestyle, and being part of a stress producing environment. Therefore, self-management of diabetes is indispensable for this community.

Since diabetes is an everlasting disease which is difficult to cure, being active about self-managing it helps lower its risks on one’s health. In order to manage this disease, it is recommended that the patients manage their stress levels, adopt healthy eating habits, and an active lifestyle. This should be done in addition to taking regular medication to cure the disease.

48% of AIs have a lower health literacy rate due to their cultural beliefs, communication styles, and language barrier [3-7]. Moreover, the adults in the AI community face various other health issues like having poor vision, lower hearing capability, and other cognitive issues relating to aging such as memory loss. These issues vary from individual to individual. Hence, a personalized management plan tool for the special needs of the members of the AI/AN community is required.

In this paper, we propose to design and evaluate a user profile ontology for the AI/AN community. The ontology is used to create an exhaustive knowledge-base to profile the users. Conceptualization of user profiling is desired to log the user context and to personalize the applications based on it [8]. User profiling can help consider user's challenges regarding personal food preferences, health conditions, cultural preferences, geographical preferences, and workout preferences to recommend individualized customized plans to manage diabetes [9,31].

Once a well evaluated ontology is created, it can be used by software developers and engineers to ultimately create a personalized tools for the American Indian/Alaskan Natives to help them manage their diabetes.

Ontologies plays a crucial role in semantic web development with the help of concepts and relationships. Ontologies provide semantics to the terms that help in creating a knowledge base which when generated is understandable by both humans as well as machines [10]. Ontologies are perceived as artifacts that support the adaptable utilization of the gathered data as well as the reuse of the same. Ontologies should not be incorrect, inconsistent or redundant in the domain of their use. One of the major advantages of the ontology is its reusability, it will be unwise to publish an ontology without thoroughly evaluating it [11]. In this paper, we use the OQuaRE evaluation framework, along with various tools like the Ontology Pitfall Scanner and others to evaluate our ontology. Ultimately, we try to compare our ontology (NAOnto) with the already evaluated ontologies to measure how it fares against them [12,13].

RELATED WORK

Personalization is based on the user's profile which is important in gathering vital information about an individual. Ontology has gained much popularity and importance in recent years for knowledge representation and it has been found to perform better in user profiling as compared to other methods of user profiling. [14].

An ontology can be called an optimal ontology if it is well evaluated. There can be various ways, criteria, and aspects on which an ontology can be evaluated.

One of the ways is to consider the ontology as a whole and inspect the ontology considering it to be a single entity. Under this classification there are various methods of ontology evaluation such as:

- Comparison Against Gold Standard – This method compares an ontology with a "gold-standard" ontology which is suitably designed for the domain of discourse.
- Application-based evaluation using this evaluation method ontology can be compared in context of an application.
- User-based evaluation - Evaluating ontology through user experiences and data driven evaluation involves comparing the ontology against existing data about the domain of the models [15-20].

Another way of evaluating the ontology is by taking into consideration that an ontology artifact comprises of various layers. For the same, Gangemi et al. provided a comprehensive approach to evaluate the ontology on three major aspects such as Structural, functional and usability profiling measures. The structural dimension concentrated on syntax and formal semantics of the ontology. Functional aspect evaluated the ontology and its component for its intended use. Usability Profiling deals with evaluation of ontology annotations i.e. meta-language that helps to understand the ontology [21].

In 2010, Vrandecic concentrated on automatic domain and task independent evaluation of web ontologies. His evaluation was comprised of several criteria that justified the methods like Accuracy, Adaptability, Clarity, Completeness, and Conciseness etc. The methods employed were structured using various aspects such as Vocabulary, Syntax, Structure, and Representation etc. [10].

Another research focuses on evaluating the ontology on various criteria with the help of metrics to evaluate the ontology. Metrics for coverage, cohesion and coupling were used to evaluate the ontology along with the experts [22].

Yao et al., In another paper adopted the software practices to build metrics in order to define and validate cohesiveness of the ontology [23].

To conclude, there are plenty of evaluation methods, but there is no standard method for evaluating ontology in an exhaustive manner.

ONTOLOGY DESIGN

What is an Ontology?

An ontology is a clear and precise way of representing the concepts of a domain which can be easily understood and processed by humans as well as software agents.

Ontology Design Phases

The design phase consists of various steps in order to build a complete and exhaustive ontology which are defined below:

- **Scope Definition:** The initial step in ontology design is describing the scope of the ontology. Scope or domain of the ontology means who are the target or the end users of the ontology. Here in our ontology we restrict our domain to the American Indian and Alaskan Native tribe people.
- **Knowledge Acquisition:** Here in this step we start gathering the information/knowledge about the target in the regular unrefined natural language which gives us the unstructured data. The data is gathered from various sources such as literature, end/target users. In order to make the study more comprehensive we surveyed the region so we could understand the area where the tribe people lived as well as interacted and discussed with domain experts to get the best possible information to frame the ontology.
- **Specification:** In this step we try to merge the above two steps to narrow and refine the information so that the engineers can build the structure out of the information and can frame the ontology. The process of knowledge acquisition and the specification is iterative and incremental which can change and evolve the information at the specification step with the incremental change in the knowledge acquired.

- **Conceptualization:** At this stage, we concluded with scope defined knowledge, and finally obtained the unstructured data. Then we used this unstructured date to create concepts and hierarchy which can ultimately be adopted in a structured format using the ontology editors. In order to understand the main concepts, we have created a Unified Modelling Language based diagram. Fig 1. Shows the UML diagram.
- **Implementation:** The knowledge of the ontology has been defined using Web Ontology Language (OWL) and we have used Protégé to design the ontology for our paper. Owl is a computational logic-based language, such that the querying of such structured data is possible by the machines/computers, and such knowledge base can be shared across the world wide web.

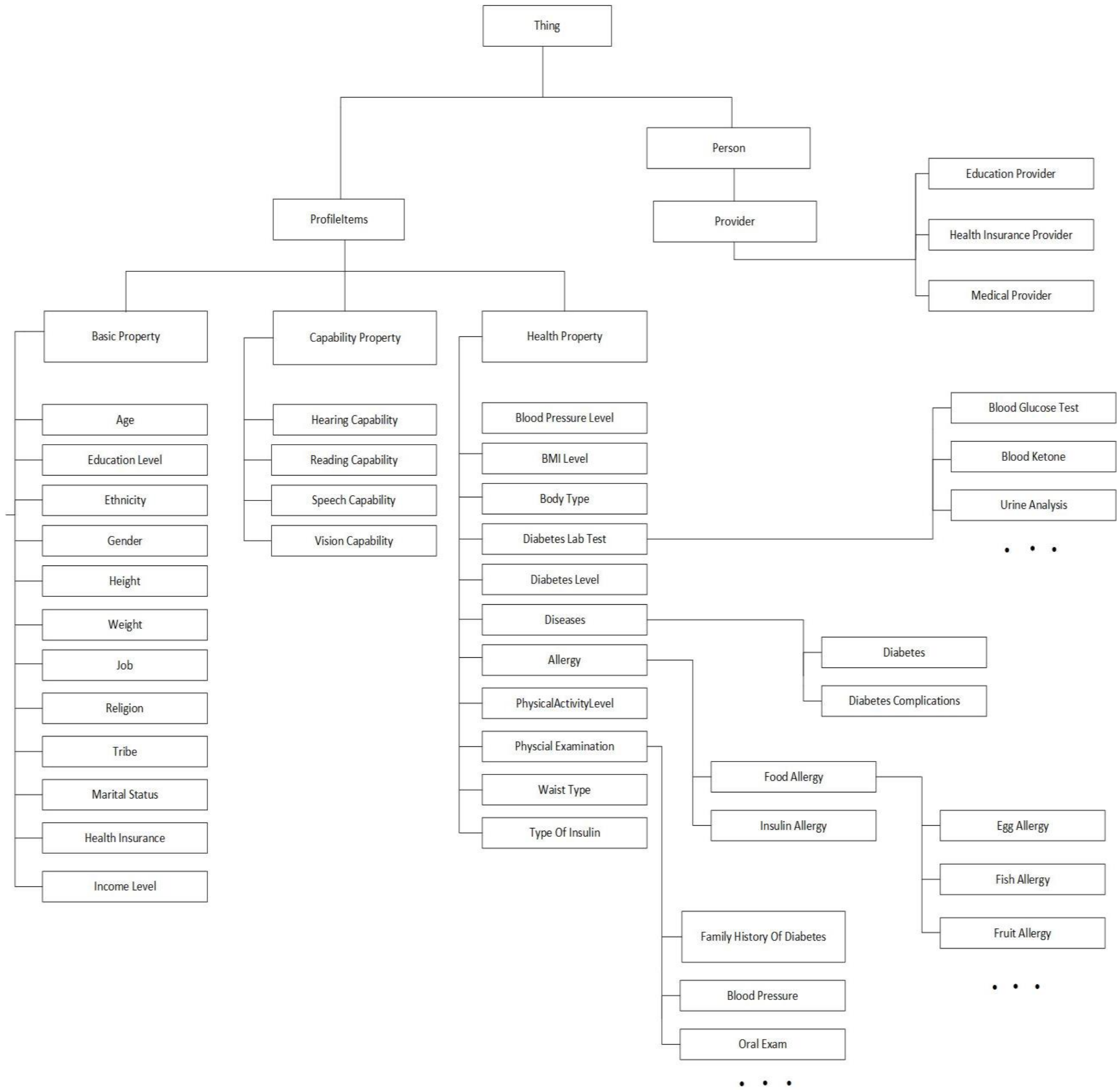

Figure 1. UML Diagram.

Ontology Description

This section presents a brief information on our NAOnto profile ontology.

Table 1. Top level classes in the profile ontology.

Class	Subclasses	Definition
Entity		A thing with distinct and independent existence.
	Person	Any patient or individual
	Provider	Any person or company that provides a service.
Profile Property		Quantifiable property values.
	Basic Property	General basic information about the patient.
	Capability Level	Property defining capability level of the patient like speech and vision.
	Health Property	This stores the general health information about the patient.

This table presents the top-level classes of the ontology that is proposed for the American Indian community.

The top two classes are Entity and Profile Property. The Entity class has two subclasses namely Person and Provider. The Person class is the most important class that contains all the users as its instances. The provider class is created to list all the people or companies that provide certain services to the patients like education, health insurance, medical providers.

The Profile Property class has all the information about the Patients, the Profile Property class has three subclasses like Basic Property, Capability Property and Health Property. The

Basic Property class has all the basic information in the form of classes about the patient like Age, Education level, Ethnicity, Gender, Health Insurance, Height, Income level etc.

The capability level class has subclasses like hearing capability, reading capability, Speech capability and vision capability. These subclass help identify the various capabilities that can be linked to the patients. Finally, the health Property helps to identify various allergies, blood sugar level, BMI level of the patients that will help us to recommend food in the most accurate and precise way.

EVALUATION

The whole purpose of ontology evaluation is to make it worth for sharing and reusing among the community members [25]. Evaluation is performing actions on the ontology to check if the system is in alignment with the requirements. Measuring the quality of ontology is useful for ontology developers as it automatically allows the ontology engineers to find the areas that need more work in order to make the ontology qualitatively useful, more over since the ontology is a shareable knowledge base, hence it is very important to assess different aspects of the ontology so users can actually make sure which ontology to use in different application/situations.

Ontology evaluation is continuously in research and there is no single best method available for ontology evaluation. Various aspects have been discussed before to assess the capability of the ontology. In this paper we have implemented a variety of methods in combination to extensively evaluate the various aspects of our ontology.

According to Gomez-Perez and Vrandecic, evaluation of ontology consists of two parts verification and validation. NAOnto has been evaluated on the similar lines. Verification of ontology informally can be understood if the ontology is built correctly, the knowledge that is added to the ontology is actually in alignment with the software artifact requirement in order to make sure that there is no problems in the structure, operability of the ontology, logical consistency of the ontology etc. [10,24]. To do the same we use OQuaRE framework, this framework qualitatively measures the aspects of cohesion, redundancy, functional adequacy, ease of its maintainability and reusability of the ontology among other things. with the help of defined metrics which give us a better idea about the ontology as a software application[12].

Other tools that have been employed to ascertain the quality of our ontology were reasoners like Fact++, HermiT, Pellet. Reasoners were employed to provide a syntactical verification of the ontology. All the complex inconsistent or incoherent axioms were discovered and corrected with the help of Onto Debug tool [25].

Validation of the ontology means if the right ontology is built [24]. The ontology with the data i.e. the knowledge base needs to be evaluated with respect to its actual use. Here we discuss about assessing our ontology not semantically or structurally, but we try to evaluate information ontology contains. We used a variety of methods to evaluate on this front. Validating the ontology with the help of experts gives the end users as well as community members the confidence to accept the ontology. Domain experts were involved continuously with the ontology engineers to guide them through the development of the ontology. We tried to query some of the competency questions that we wanted as an absolute requirement needed to be fulfilled by our ontology, and we were able to fetch meaningful results. Finally, application-based validation of the ontology was done with the help of the mobile application built with integration of this ontology, we created a variety of use cases and after performing multiple tests we found the results to be satisfactory.

Verification Process

Technical Evaluation/Verification of the Ontology: Ontology verification means that the hierarchy of the concepts must be consistent according to the real world. [24].

The authors propose various independent methods to cover all the aspects of the ontology verification. OQuaRE framework, Ontology Debugger tool, OOPS! Tool.

OQuaRE

OQuaRE comprises of characteristics suggested by SQuaRE framework as well as the state-of-the-art methods from the ontology evaluation community to get the exhaustive quality model for ontology evaluation [12, 33]. Characteristics such as Structural, Functional Adequacy, Reliability, Operability, Maintainability are the prime characteristics of the OQuaRE framework. Each characteristic has multiple sub characteristics that are evaluated based on various defined metrics as well as experts.

Below mentioned are a few characteristics and sub characteristics described along with their respective evaluation techniques.

- **Structural Quality**: This attribute evaluates if the ontology is structurally sound. Ontology quality factors such as consistency which attests the naming conventions that are used in the ontology, redundancy that suggests if the ontology is free of non-repetitive terms, formalization, and other quality factors are utilized to ascertain this fact.
    - ***Sub Characteristics:***
        - **Cycles**: Cycles in an ontology or any other software artifact imply sign of poor design. Hence, the authors along with the experts manually inspected to make sure the ontology is free of cycles.
        - **Domain Coverage**: The Domain coverage of the ontology measures the extent to which the ontology encloses the domain of use, our ontology was exhaustively evaluated on this aspect by our Ontology experts.
        - **Structural Accuracy:** This determines if the terms used in the ontology are correct. With the help of experts, structural accuracy of the ontology was evaluated.

        - Various other sub characteristics such as Tangledness, Formal relations support, Cohesion were evaluated with the help of metrics like RROnto, ANOnto, TMOnto, LCMOnto, more details are listed in Table 3.
- **Functional Adequacy**: This characteristic determines the ability of the ontology to satisfy functional necessities.
    - ***Sub Characteristics:***
        - Knowledge acquisition representation: This describes if the ontology is capable to represent the knowledge acquired from the domain. Various metrics such as ANOnto, RROnto were used to evaluate this sub characteristic.
        - Classifying instances: Represents the degree to which the ontology individuals can be associated with concepts.
        - Knowledge Reuse: It explains the extent to which the ontology knowledge can be reused to build other artifacts. Metrics such as ANOnto, AROnto etc. were used to evaluate this sub characteristics.
        - Classifying instances and Precision characteristics were evaluated in collaboration by the ontology engineers and experts.
- **Compatibility**: The capacity of two or more ontologies to share knowledge, while sharing the same domain, to perform their necessary functions.
    - ***Sub Characteristics:***
        - **Replaceability:** The degree to which this ontology can be replaced with of another ontology for the similar goal and domain. Metrics such as WMCOnto, DITOnto etc. were used to evaluate this sub characteristic.

        - **Interoperability**: Degree to which the ontology can be used with combining knowledge from more than one ontology was evaluated with the help of experts.

- **Transferability**: Degree to which the ontology can be transferrable from one domain to another domain.
    - ***Sub Characteristics:***
        - **Adaptability**: Degree to which the ontology can be transformed or modified to a distinct domain without necessitating any external effort. Metrics used to evaluate adaptability were WMCOnto, DITOnto, RFCOnto etc.
        - **Portability:** This refers to the degree to which ontology can be shared between multiple software or hardware domains. This sub characteristic was evaluated with the help of domain experts.
- **Operability:** Amount of effort required by the users to use the ontology.
    - ***Sub Characteristics:***
        - **Appropriate Recognizability:** This enables users to recognize whether the ontology is capable enough to discover faults.
        - **Ease of Use:** Helps to know how easy it is to operate and use the ontology.
        - **Helpfulness:** Describes helpfulness of the ontology while in use. These sub-characteristics were carefully evaluated with the help of the experts.

        - **Learnability:** This sub characteristic helps to determine how easy is to learn the use of the ontology. This sub characteristic was evaluated with the help of metrics such as WMCOnto, LCOMOnto, RFCOnto etc.

- **Performance Efficiency:**
    - ***Sub Characteristics:***
        - **Response time:** It measures the degree to which ontology provides appropriate response processing times and throughput rates when operated under asserted conditions. This sub characteristic was evaluated using our application along with the experts.
        - **Resource Utilization:** Degree to which the ontology performs and utilizes resources when used in an application.
- **Maintainability**: Ability of ontology to be altered with respect to the changes in requirements or functional specifications.

Table 2. Maintainability sub characteristics and associated metrics.

Sub-characteristics	Definition	Metrics used for evaluation.
Modularity	Describes to what degree ontology consists of distinct elements, such that changes in one element has minimum to low impact on other elements.	WMCOnto, CBOnto
Reusability	Extent to which a section of ontology can be used in more than one ontology.	WMCOnto, CBOnto, DITOnto, NOCOnto etc
Analyzability	Amount of errors or sources of errors that can be diagnosed in an ontology.	WMCOnto, CBOnto, DITOnto, CBOnto, NOCOnto etc
Changeability	Describes how easily the ontology can be changed.	WMCOnto, CBOnto, DITOnto, RFCOnto, NOMOnto, NOCOnto etc
Modification stability	Checks the stability of the ontology after modification.	RFCOnto, NOMOnto, NOCOnto
Testability	Asses the validity of the modified ontology.	WMCOnto, RFCOnto, NOMOnto, CBOnto etc

Metrics in Consideration

Below are a few mentioned metrics that were used in the evaluation of the various sub characteristics.

Table 3. Description of metrics.

Metrics	Description
LCOMOnto (Lack of Cohesion in Methods it describes the semantic and conceptual relatedness of classes)	The length of the path from the leaf class i to Thing, and m is the total number of paths in the ontology.
CBOOnto (Coupling between Objects)	It is the average number of the direct parents per class minus the relationships of thing.
TMOnto (Used to calculate tangledness)	Mean number of parents per class.
NACOnto (Number of Ancestor Classes)	Mean number of ancestor classes per leaf class. It is the number of direct super classes per leaf class.
RROnto (Properties Richness)	Number of properties defined in the ontology divided by the number of relationships and properties.
INROnto (Relationships per class)	Mean number of relationships per class.
RFCOnto (Response for a class)	Number of properties that can be directly accessed from the class.
NOMOnto (Number of properties)	Number of properties per class.
CROnto (Class Richness)	Mean number of instances per class.
NOCOnto (Number of Children)	It is the number of relationships divided by the number of classes minus the relationships of thing.
DITOnto (Depth of subsumption hierarchy)	Length of the largest path from Thing to a leaf class.

Evaluation of a sub-characteristic depends on its associated metrics as described above. Value of a particular metric can positively affect or negatively affect the value of the associated sub-characteristics. One quality metric can be associated to more than one sub-characteristic. For example, LCOMOnto - Lack of Cohesion in Methods is a factor in sub-characteristics like Knowledge reuse, Learnability, Analyzability etc.

Metric values generated could be absolute or could be relative. As per, SQuaRE guidelines values of the metrics should be in the range of 1 to 5. Where 1 means "not acceptable", 3 is "minimally acceptable" and 5 means "exceeds requirement".

Higher values of the metrics may not correspond to a high-quality score after mapping the value according to OQuaRE range of 1 to 5. Metrics with absolute value for them the mapping in the OQuaRE was done based upon the meaning of the metrics. For the Relative score metrics, one unit in the OQuaRE corresponds to 20%.

Reasoner

Reasoner is an inference engine that is used to infer new information from the ontology that it contains. Reasoner are basically used for consistency checking in the ontology i.e. it helps to find if all the axioms are consistent with the knowledge added in the ontology. Since our ontology is written in Owl using Protege we used Pellet reasoner to verify the logical consistency of the ontology. To ascertain the logical consistency and syntactical verification we iterated our ontology through other reasoners as well such as HermitT reasoner, Pellet Reasoner and through FacT++ reasoner [27].

Ontology Debugger

Ontology was assessed using the Onto Debug plugin. It is a plugin available with the Protégé software, this plugin helps in identifying the more complex inconsistent axioms which cannot be easily handled by the reasoner. We found our ontology to be coherent and consistent both structurally and logically as per Ontology Debugger.

Oops

It is one of the famous online ontology verification tools which enlists various common ontology pitfalls. Our ontology was iterated multiple times using Oops to detect all possible pitfalls. A common issue detected was with the creation of synonymous classes. For example, when we define a car and a motorcar as two separate classes in our ontology, the two classes essentially mean the same. Hence, creating these two classes in the ontology would be a sign of inconsistency. Detecting this issue would be difficult for the reasoner or the ontology debugger, but it is possible to discover it using Oops . Other common pitfalls detected by Oops are determining the missing annotations, detecting cycles in the ontology, finding the missing properties, and missing relationships in the ontology etc. After analyzing our ontology, we discovered various other pitfalls associated with it such as missing annotations, 32 cases of missing domain or range, and 42 cases of missing inverse relationships. We also identified an issue with the ontology license. As per the suggestions from the Oops framework, we added symmetric and transitive object properties, license information, and metadata. Relevant inverse relationships were added and the missing domain/range problem was solved. After running multiple iterations with Oops, we were able to create an ontology free from all major pitfalls. Figure 2 describes all the pitfalls that were encountered while evaluating the ontology with this tool.

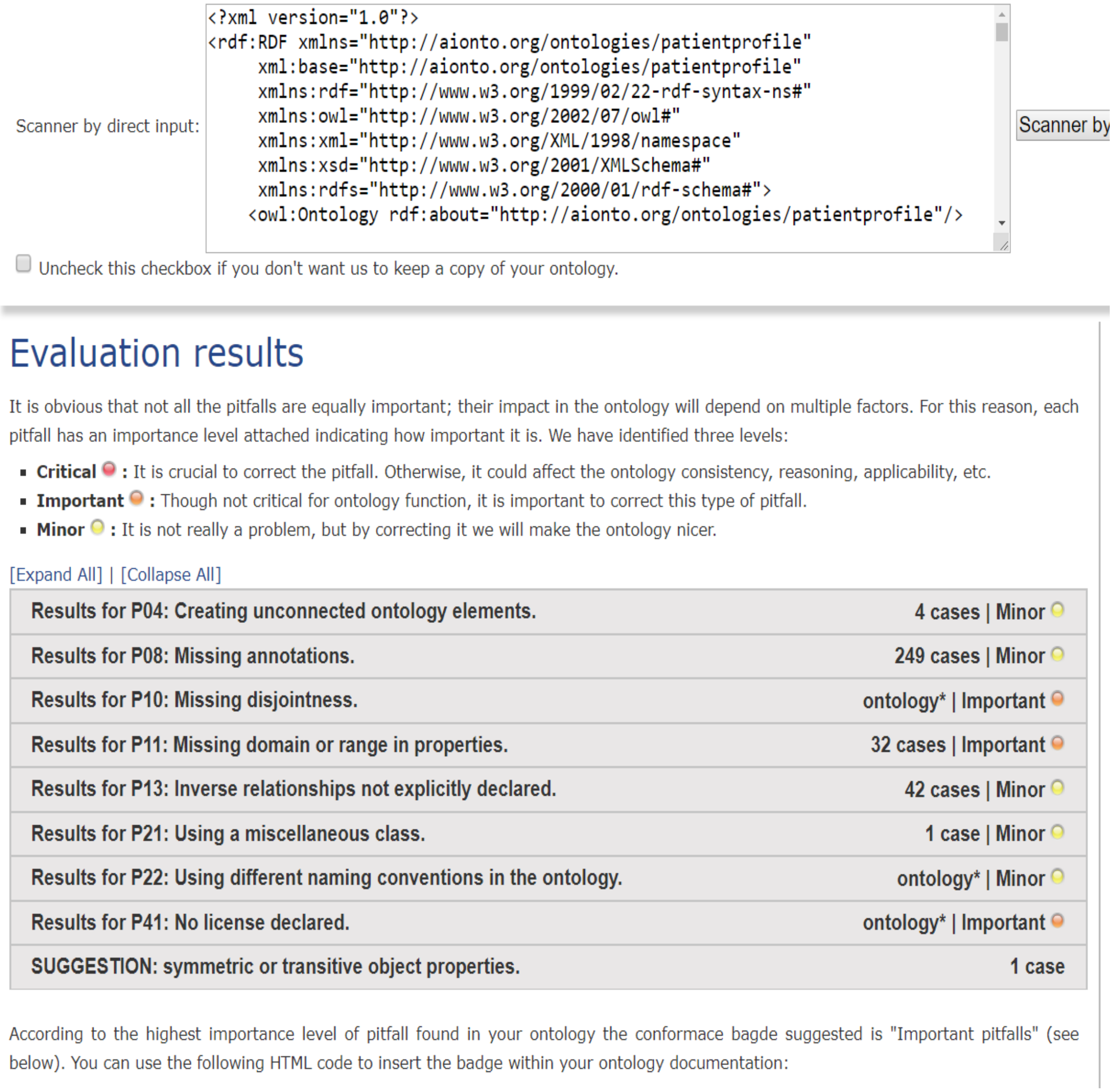

Figure 2. Ontology Verification with OOPS.

Validation Process

The most appreciated form of ontology evaluation for taxonomy, relationships and ultimately the overall structure with domain knowledge validation is by the experts or by the end users.

Competency Questions

Competency questions are set of natural language sentences that are expected by the ontology to answer. The accountability of the ontology to answer these questions are a functional requirement for the ontology. We designed the below mentioned questions to check and validate our ontology whether the ontology is capable of querying and returning the results for the desired questions. [28,29]

Question: “Find single Female patients in Lower Sioux tribe in Minnesota whose age is under 30 who weigh more than 170 lbs. and have diabetes.”

Query: This was employed to the ontology to answer the above competency question:

```
SELECT ?user ?Age ?Weight ?Diabetes
WHERE {
?user a :Person .
?user :hasGender :Female .
?user :hasMaritalStatus :Single .
?user :hasTribe :LowerSioux .
?user :hasAge ?Age .
?user :hasWeight  ?Weight .
?user :hasDiabetes ?Diabetes .
FILTER
(
?Age < 30 && ?Weight >170
)
```

Another example where we model a query for our ontology to answer would be as follows:

Question: "Find all the people in the Lower Sioux tribe of Minnesota with type1 diabetes who are above age of 50 with (Rock concert) low hearing and (Frustration Reading Level) reading capacity, and low education level (Primary Education) and low-income level."

Query: This was employed to the ontology to answer the above competency question:

```
SELECT ?user
WHERE {
?user a :Person .
?user :hasTribe :LowerSioux .
?user :hasAge ?Age .
?user :hasDiabetes ?Diabetes .
?Age :hasAgeValue ?AgeVal .
?user :hasHearingCapabilityLevel ?hearinglevel .
?user :hasReadingCapabilityLevel ?readinglevel .
?user :hasEducationLevel   ?educationlevel .
?user :hasIncomeLevel  ?incomelevel .
FILTER
(
?AgeVal>50 && ?hearinglevel=:RockConcert && ?readinglevel=:FrustrationReadinglevels &&
?educationlevel=:PrimaryEducation && ?incomelevel=:LowerClassIncome
)}
```

Other competency questions which our ontology was capable of answering were:

- How many of the people have type 2 diabetes and have lower class income or no jobs.
- List of all the Health Insurance Providers.
- List of all the Education and Medical Providers. Etc.

Use Cases/Test Cases

In order to check if our ontology is capable of fulfilling the desired goals of information retrieval, querying etc. we made the ontology run through a few test cases with the help of our mobile application such as:

Use Case 1: Mark is an obese 32 years old single man, suffering from diabetes type 2. He regularly checks his blood pressure, according to American College of Cardiology (ACC)/American Heart Association (AHA) hypertension guideline reflects a BP goal <130/80 mm Hg in patients with diabetes [31]. Mark receives a warning within the application whenever he tries to enter blood pressure, which is above the defined limit, which have tried to capture in the form of screenshots.

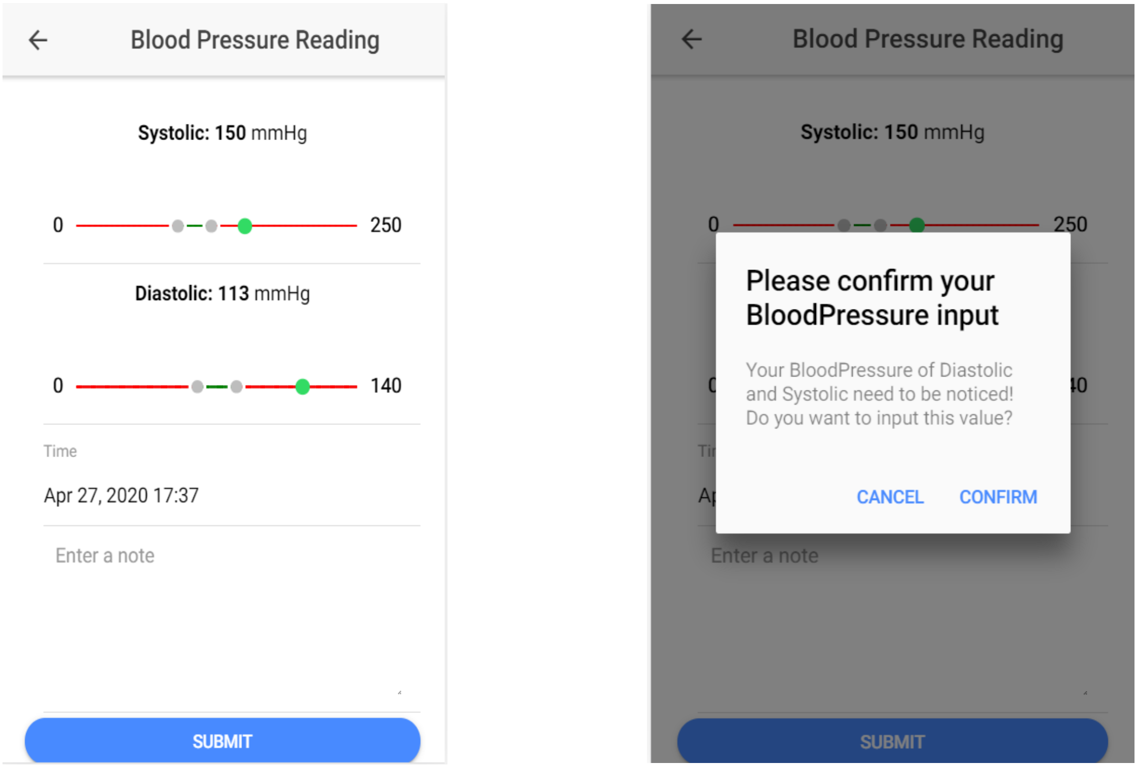

Figure 3. Blood Pressure Warning.

Use Case 2: Selena is 28 years old women, suffering from diabetes who checks her blood glucose level regularly, whenever for example blood glucose level after meal should be less than 180 mg/dl [32]. A warning is sent to the patient if the levels are dangerously higher than the specified limits and the provider as well can see the blood glucose levels situation of their respective patients.

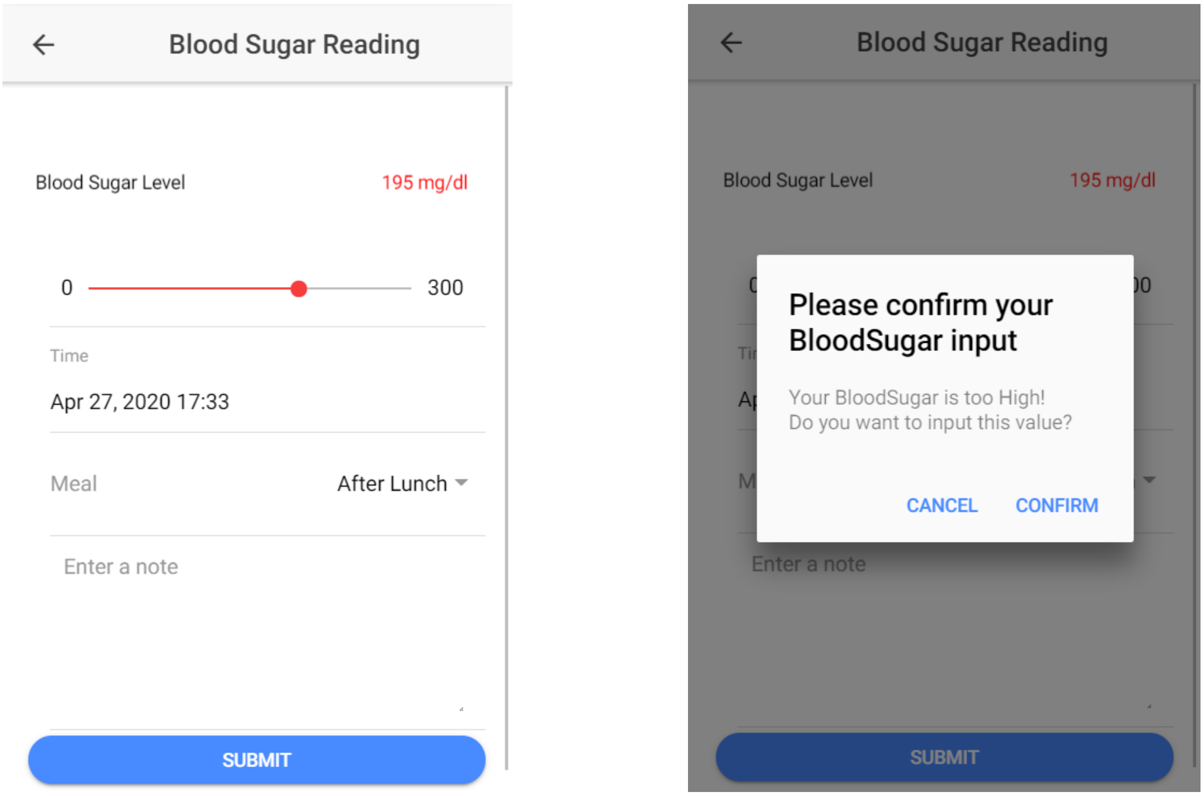

Figure 4. Blood Sugar Warning.

RESULTS

We iterated our ontology through the OQuaRE framework for multiple times until we obtained the final best results, which we eventually compared with the ontology quality metrics that are enumerated by the OQuaRE case study[1]. We have compared the values of our ontology metrics and found our ontology to be performing on an average better than the listed ontologies [33].

Table 4. Results after evaluation of metrics for each iteration.

Characteristics	Iteration 1 (V1)	Iteration 2 (V2)	Iteration 3 (V3)
Structural	4.33	4.67	4.33
Functional Adequacy	3.75	3.75	3.68
Maintainability	4.50	4.31	4.58
Reliability	2.63	3.00	2.75
Operability	3.83	3.50	4.00
Transferability	4.50	4.25	4.75
Compatibility	4.00	4.00	4.00

The final version of the ontology is solid structurally, and it can guide search processes and can provide a sematic context to evaluate which data is wanted by the user.

Below mentioned are results of our ontology characteristics evaluation result as compared to other standard ontologies.

[1] The material in this chapter was co-authored by Vikram Pandey, Shadi Alian, and Dr. Jen Li. After reviewing the findings of each iteration, Vikram Pandey was responsible for the revision and improvement of the ontology. Shadi Alian had the primary responsibility of programmatically obtaining the metric values in the aforementioned iterations and analysis of the results .Dr. Jen Li served as proofreader and supervised the experiment.

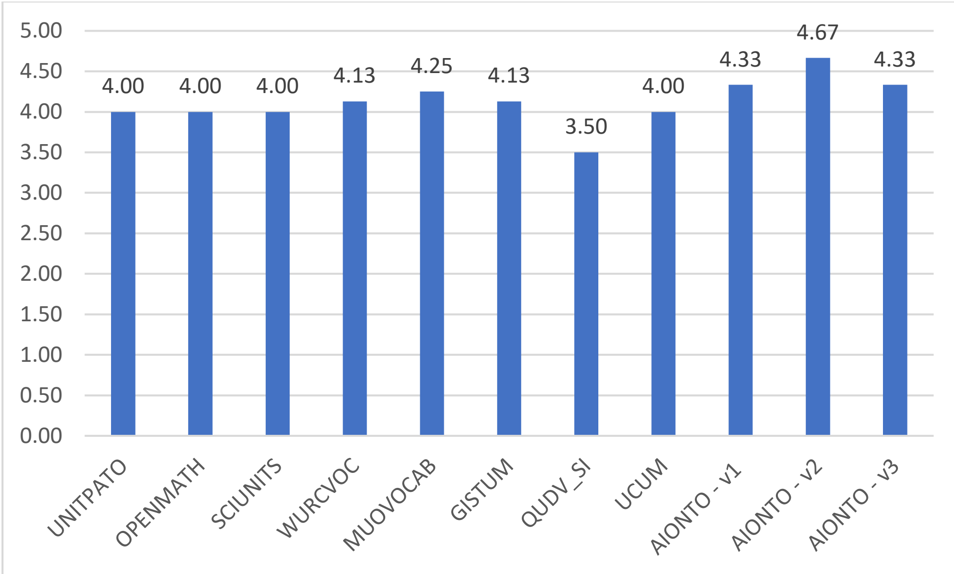

Figure 5. Structural Evaluation.

Ontology structure is important to evaluate the manually constructed ontologies like the one that we have discussed in this paper. Structural evaluation of the ontology pertains to the evaluation of the formal structure of the ontology [23]. The quantitative value of the structural measure was calculated using the OQuaRE framework and were compared with the famous ontologies listed in the framework where we found the final iteration of our ontology being at par with them.

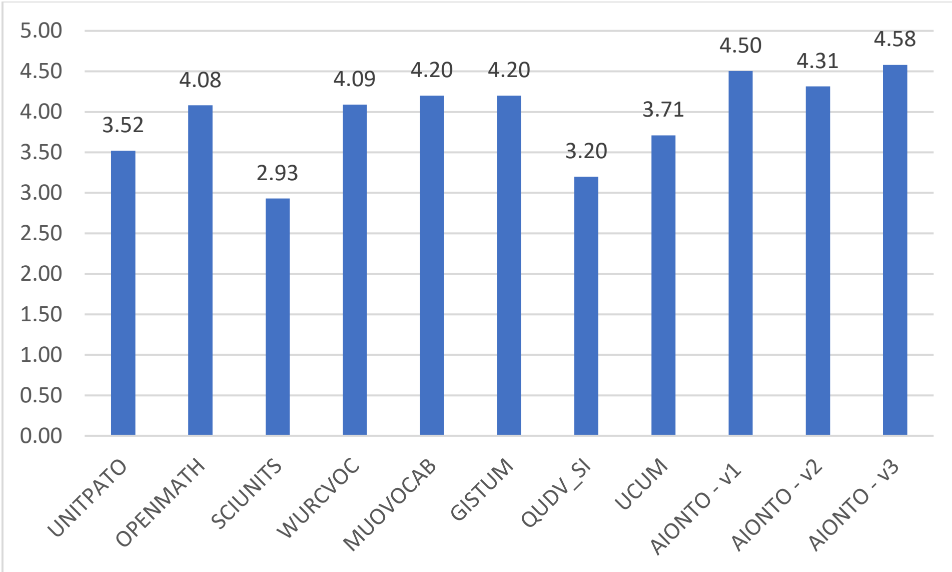

Figure 6. Maintainability Evaluation.

Maintainability characteristic was evaluated using the metrics provided by the framework. We calculated the values and found the value for the third iteration of our ontology doing exceptionally better than the ontologies that we compared with.

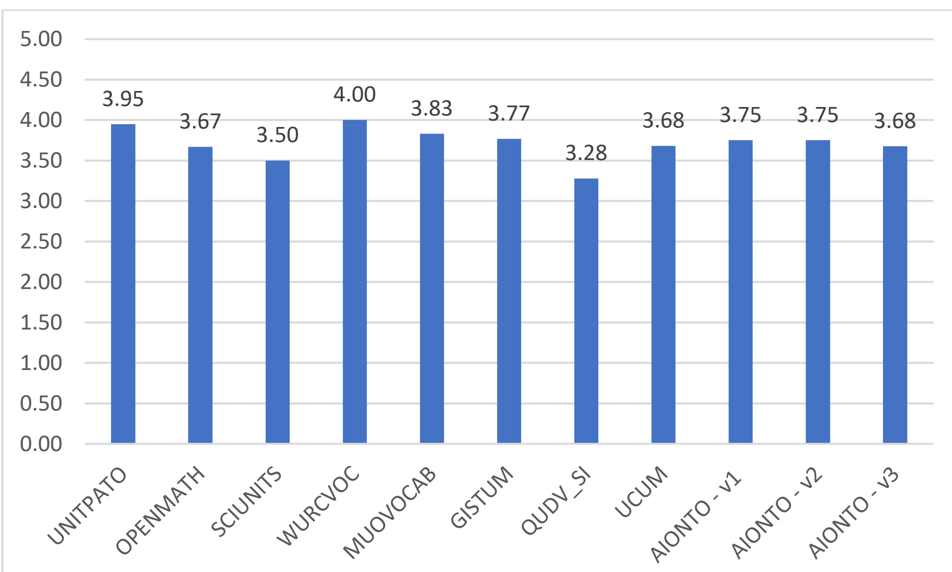

Figure 7. Functional Adequacy Evaluation.

We evaluated the Functional adequacy of NAOnto. Our ontology as per the framework tuned out to be on par when compared with the various standard ontologies.

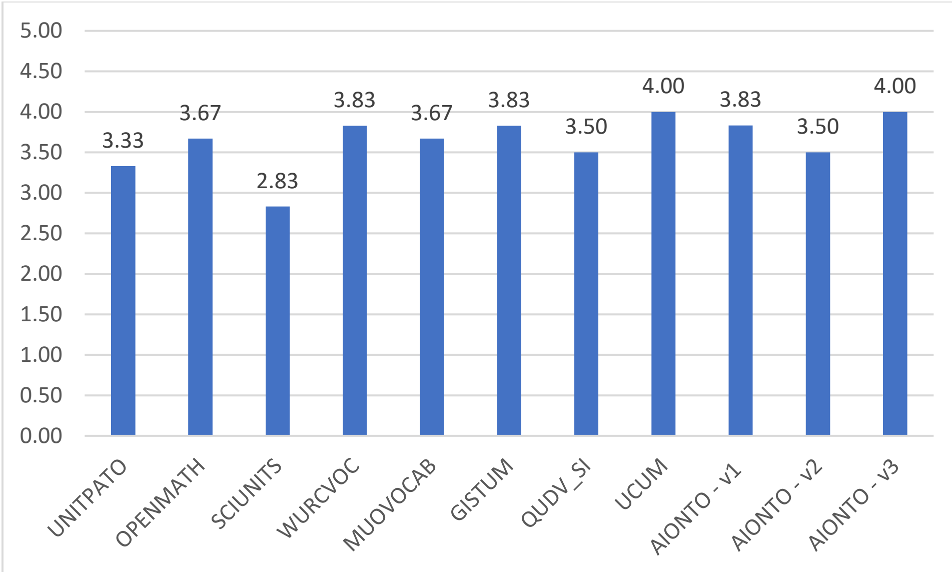

Figure 8. Operability Evaluation.

Operability here is basically quantified value for efforts needed for using the ontology, by an individual or by a stated or implied set of users. In this context we found our ontology doing exceptionally better than all the other ontologies under consideration.

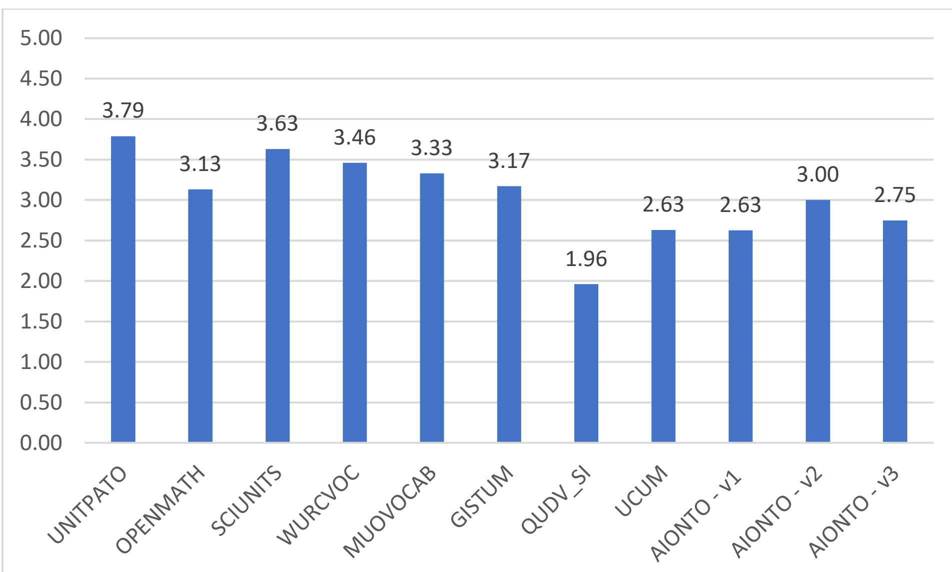

Figure 9. Reliability Evaluation.

Our ontology was evaluated to check if it can perform under stated conditions as per OQuaRE framework, we found our final iteration value doing relatively better than few of the ontologies and overall value was acceptable as per the framework.

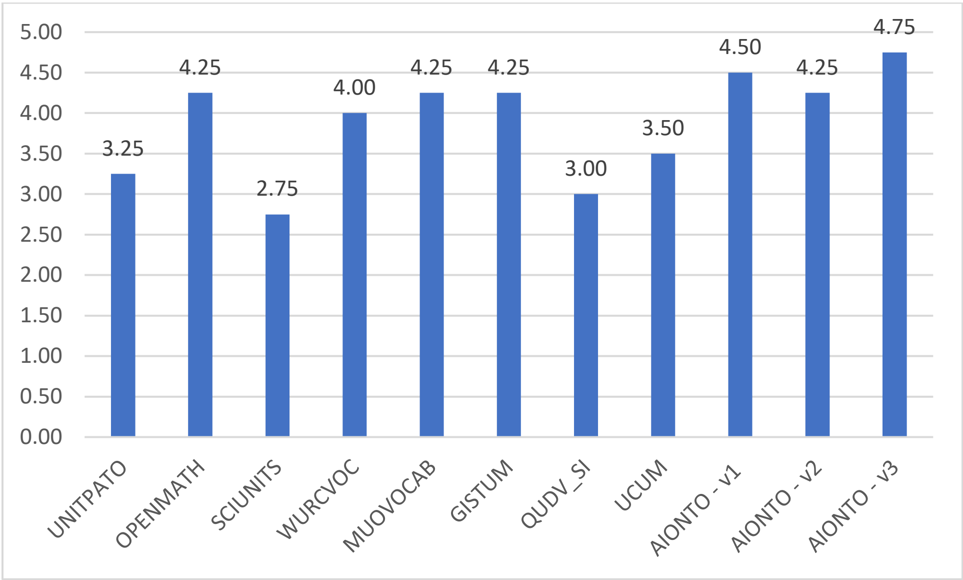

Figure 10. Transferability Evaluation.

Transferability of the ontology was evaluated, and the final version of our ontology outperformed all the ontologies that were taken in consideration for comparison.

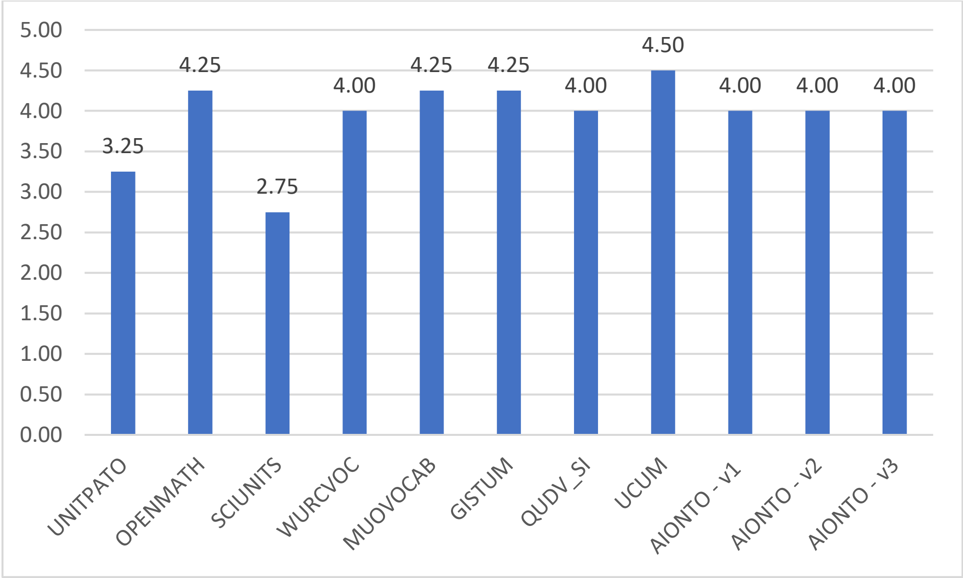

Figure 11. Compatibility Evaluation.

Our ontology was evaluated for the compatibility. In this context as well out ontology fared on an average better than most of the other ontology in consideration.

DISCUSSION AND CONCLUSION

After thorough evaluation, we can conclude that our ontology can be used in place of a different ontology for the same purpose in the same language for creating, querying, and inferring of data. Our ontology allows users to detect faults and use its knowledge-base for building other ontologies. This ontology can be easily tested and validated. The ontology's knowledge-base can also be effectively reused and adapted for different specified environments. The components of this ontology can be modified with minimal effects over the rest of the components.

In our evaluation using the OQuaRE framework, we used same metrics to evaluate different characteristics. For example, to evaluate reusability characteristic one of the metric used was NOCOnto which was again used to evaluate the changeability characteristic, but in a different manner. This metric when used to evaluate changeability characteristics had to be used as a higher value whereas while evaluating the reusability it had to be reversed and a lower value had to be used. Similarly to evaluate other characteristics we had to do the same process. Hence, we had to strike a balance between various metrics which is why our value for reliability is on the lower side as compared to other values in our ontology evaluation. Overall, our ontology's mean value was higher than the mean values of the other ontologies under comparison.

REFERENCES

1. Centers for Disease Control and Prevention. 2020. National Diabetes Statistics Report: Estimates of Diabetes and Its Burden in the United States. https://www.cdc.gov/diabetes/pdfs/data/statistics/national-diabetes-statistics-report.pdf
2. McLaughlin, S. 2010. Traditions and diabetes prevention: a healthy path for Native Americans. Diabetes Spectrum. https://spectrum.diabetesjournals.org/content/diaspect/23/4/272.full.pdf
3. White, S. 2008. Assessing the nation's health literacy: Key concepts and findings of the National Assessment of Adult Literacy (NAAL). American Medical Association Foundation. https://trove.nla.gov.au/work/31750077?q&versionId=38518580
4. Nielsen-Bohlman, L., Panzer, A. M. & Kindig, D. A. 2004. Health literacy: a prescription to end confusion. Washington (DC): Institute of Medicine of the National Academies. https://www.ncbi.nlm.nih.gov/pubmed/25009856
5. Weiss, B. D. 2007. Health Literacy A Manual for Clinicians. American Medical Association Foundation. http://lib.ncfh.org/pdfs/6617.pdf
6. Centers for Disease Control and Prevention. 2009. Improving Health Literacy for Older Adults. US Department of Health and Human Services Centers for Disease Control and Prevention. https://www.cdc.gov/healthliteracy/pdf/olderadults-508.pdf
7. Verney, S. P., Jervis, L. L., Fickenscher, A., Roubideaux, Y., Bogart, A. & Goldberg, J. 2008. Symptoms of depression and cognitive functioning in older American Indians. Aging and Mental Health. https://www.ncbi.nlm.nih.gov/pubmed/18297485

8. El Allioui, Y. & El Beqqali, O. 2012. User profile Ontology for the Personalization approach. International Journal of Computer Applications. https://pdfs.semanticscholar.org/5ded/250343875ad652653ca48dd3d4a0c2eb07b3.pdf
9. Alian, S., Li, J. & Pandey, V. 2018. A Personalized Recommendation System to Support Diabetes Self-Management for American Indians. IEEE Access. https://ieeexplore.ieee.org/document/8539994
10. Vrandecic, D. 2010. Ontology Evaluation [PhD thesis]. KIT, Karlsruhe. https://publikationen.bibliothek.kit.edu/1000018419/1355289
11. Staab, S., Gómez-Pérez, A., Daelemana, W., Reinberger, M. L. & Noy, N. F. 2004. Why evaluate ontology technologies? Because it works!. IEEE Intelligent Systems. https://ieeexplore.ieee.org/document/1333038
12. Duque-Ramos, A., Fernández-Breis, J. T., Stevens, R. & Aussenac-Gilles, N. 2011. OQuaRE: A SQuaRE-based approach for evaluating the quality of ontologies. Journal of Research and Practice in Information Technology. https://search.informit.com.au/documentSummary;dn=265844843145749;res=IELAPA
13. Poveda-Villalón, M., Gómez-Pérez, A. & Suárez-Figueroa, M. C. 2014. Oops!(ontology pitfall scanner!): An on-line tool for ontology evaluation. International Journal on Semantic Web and Information Systems (IJSWIS). https://www.igi-global.com/article/oops-ontology-pitfall-scanner/116450
14. Sosnovsky, S. & Dicheva, D. 2010. Ontological technologies for user modelling. International Journal of Metadata, Semantics and Ontologies. https://dl.acm.org/doi/abs/10.1504/IJMSO.2010.032649

15. Brewster, C., Alani, H., Dasmahapatra, S. & Wilks, Y. 2004. Data driven ontology evaluation. International Conference on Language Resources and Evaluation. http://oro.open.ac.uk/20045/
16. Hlomani, H. & Stacey, D. A. 2013. Contributing Evidence to Data-driven Ontology Evaluation - Workflow Ontologies Perspective. International Conference on Knowledge Engineering and Ontology Development – Volume 1: KEOD. https://www.semanticscholar.org/paper/Contributing-Evidence-to-Data-driven-Ontology-Hlomani-Stacey/72ec7f89a3c008e9cdcebf09515a25d37ba159e9
17. Brank, J., Grobelnik, M., & Mladenic, D. 2005. A survey of ontology evaluation techniques. Conference on Data Mining and Data Warehouses. (SiKDD) http://citeseerx.ist.psu.edu/viewdoc/summary?doi=10.1.1.101.4788
18. Ensan, F., & Du, Weichang. 2013. A semantic metrics suite for evaluating modular ontologies. Information Systems. https://dl.acm.org/doi/10.5555/2451993.2452241#sec-ref
19. Maedche, Er., & Staab. S. 2002. Measuring similarity between ontologies. European Conference on Knowledge Acquisition and Management (pp. 251– 263). http://citeseerx.ist.psu.edu/viewdoc/summary?doi=10.1.1.131.5761
20. Porzel, R., & Malaka. R. 2004. A task-based approach for ontology evaluation. Workshop on Ontology Learning and Population. http://citeseerx.ist.psu.edu/viewdoc/download?doi=10.1.1.93.6109&rep=rep1&type=pdf
21. Gangemi, A., Catenacci, C., Ciaramita, M., Lehmann, J., Gil, R., Bolici, F., & Strignano, O. 2005. Ontology evaluation and validation: An integrated formal model for the quality diagnostic task. Technical Report, Laboratory of Applied Ontologies.

https://www.semanticscholar.org/paper/Ontology-evaluation-and-validation-An-integrated-Gangemi-Catenacci/0e93dd28af4b6596cacba6c33369ac8023324baa

22. Ouyang, L., Zou, B., Qu, M. & Zhang, C. 2011. A method of ontology evaluation based on coverage, cohesion and coupling. 2011 Eighth International Conference on Fuzzy Systems and Knowledge Discovery (FSKD). https://ieeexplore.ieee.org/document/6020046
23. Yao, H., Orme, A. M. & Etzkorn, L. 2005. Cohesion metrics for ontology design and application. Journal of Computer science. https://www.thescipub.com/abstract/?doi=jcssp.2005.107.113
24. Gómez-Pérez, A. 2004. Ontology Evaluation. Handbook on ontologies (pp. 251-273). Springer, Berlin, Heidelberg. https://link.springer.com/chapter/10.1007/978-3-540-24750-0_13
25. Schekotihin, K., Rodler, P., Schmid, W., Horridge, M. and Tudorache, T., 2018. A Protégé Plug-In for Test-Driven Ontology Development. In International Conference on Biological Ontology. http://ceur-ws.org/Vol-2285/ICBO_2018_paper_9.pdf
26. Lovrencic, S. & Cubrilo, M. 2008. Ontology evaluation-comprising verification and validation. Central European Conference on Information and Intelligent Systems. http://archive.ceciis.foi.hr/app/index.php/ceciis/2008/paper/view/53/98
27. El-Sappagh, S., Kwak, D., Ali, F. & Kwak, K. S. 2018. DMTO: a realistic ontology for standard diabetes mellitus treatment. Journal of biomedical semantics. https://link.springer.com/article/10.1186/s13326-018-0176-y
28. Ren, Y., Parvizi, A., Mellish, C., Pan, J.Z., Van Deemter, K. & Stevens, R. 2014. Towards competency question-driven ontology authoring. European Semantic Web Conference (pp.

752-767). Springer. https://www.semanticscholar.org/paper/Towards-Competency-Question-Driven-Ontology-Ren-Parvizi/0c9124fc1dc8fbf982412471c724ea9df4385ce5

29. Alian, S., Li, J. & Pandey, V. 2018. A Personalized Recommendation System to Support Diabetes Self-Management for American Indians. IEEE Access. https://ieeexplore.ieee.org/document/8539994

30. Li, J. & Alian, S. 2018. Design and Development of a Biocultural Ontology for Personalized Diabetes Self-Management of American Indians. IEEE 20th International Conference on e-Health Networking, Applications and Services (Healthcom). https://ieeexplore.ieee.org/document/8531107

31. Carey, R. M. & Whelton, P. K. 2018. The 2017 American College of Cardiology/American Heart Association hypertension guideline: a resource for practicing clinicians. Annals of internal medicine. https://annals.org/aim/article-abstract/2670321

32. WebMD. 2020. Normal Blood Sugar Levels for Adults with Diabetes. https://www.webmd.com/diabetes/guide/normal-blood-sugar-levels-chart-adults

33. Duque-Ramos, A., Boeker, M., Jansen, L., Schulz, S., Iniesta, M. & Fernández-Breis, J. T. 2014. Evaluating the good ontology design guideline (GoodOD) with the ontology quality requirements and evaluation method and metrics (OQuaRE). PloS one. https://journals.plos.org/plosone/article?id=10.1371/journal.pone.0104463