RESEARCH ARTICLE

The Semantic Web of Digital Technology and Learning in the 21st Century for Undergraduate using Ontology Techniques

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Abstract

In the 21st century, digital technology has become integral to daily life, significantly impacting the skills and knowledge of undergraduate students. This research aims to develop a Semantic Web for learning digital technology in the 21st century by employing ontology techniques to enhance the efficiency of information retrieval. The system is designed to offer flexible learning, adaptable to students' needs, and focuses on categorizing content into three main classes and twelve subclasses. These classes define relationships using four object properties to connect main classes, subclasses, and instances, and four data type properties to link instances with data and relationships between digital technologies. This approach clarifies information and makes it more relevant for undergraduate students. Despite the advantages of ontology techniques in improving information retrieval and recommendation processes, challenges remain due to the complexity of constructing data relationships and establishing rules for data storage and retrieval. Effectively managing semantic data requires specialized knowledge to ensure accurate and efficient outcomes. The ontology knowledge base primarily consists of digital technology, innovation, and digital skills. Based on evaluations by three experts, the Semantic Web for digital technology learning in the 21st century, developed using ontology techniques, was rated at a very good level ($\bar{x} = 4.52$, S.D. $= 0.19$). The system's performance was also validated, showing precision at 96.25%, recall at 92.08%, and an F-measure of 95.29%, indicating its effectiveness in supporting learning through digital technology.

1. Introduction

The 21st century has seen profound changes in the relationship between digital technologies and learning, with the rapid evolution of technological capabilities fundamentally changing the way individuals engage and acquire knowledge. In education, a well-understood approach to digital technologies has become a key component in developing the skills and knowledge of undergraduate students, who need to prepare for the rapidly changing world of work. The application of digital technologies such as cloud computing, artificial intelligence (AI), and the Internet of Things (IoT) in teaching and learning not only provides students with a flexible and adaptive learning experience but also prepares them for a knowledge-driven society. These digital technologies build critical skills, benefiting future careers and advancements. Therefore, it is important to design education and technology systems that support undergraduate students, allowing them to use digital technologies to their fullest potential in learning and self-development (Taherdoost, 2022). Studying data from multiple sources can often be complex and fragmented, requiring students to spend time searching for and organizing information from different sources. Using ontologies is a way to help compile these data in a clear and systematic manner that undergraduates find easy to read and understand.

There are diverse trends in digital technology today that have different functions. These include cloud computing, IoT, AI, blockchain, big data analytics, virtual reality (VR), 5G networks, sensor networks, social media, and robotics (Martinelli et al., 2021; Taherdoost, 2022; Rindfleisch et al., 2017). The emergence

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and widespread use of digital technologies have greatly supported many areas of work, including the use of new digital technologies in industry (Martinelli et al., 2021). The IoT platform allowed health authorities to access data to help monitor the spread of the COVID-19 virus (Ting et al., 2020). Blockchain is a distributed transaction database technology that connects data (Chain) and ensures reliability and security with regard to data or transactions of a digital nature (Głowacka et al., 2021; Beck et al., 2017). Big data enables organizations to collect and analyze large amounts of data. Various sources affect the functioning of businesses and organizations by enabling smarter decisions to achieve identified goals (Qi et al., 2022).

According to a review of the literature on tools that disseminate knowledge content, websites serve as effective sources of information. In particular, Semantic Web technology was proposed by Berners-Lee et al. (2001) as a means to disseminate semantic knowledge content. Semantic Web technology is designed to provide information on websites that can be automatically understood and analyzed. For a computer to read and understand the meaningful content of a website, elements such as eXtensible Markup Language (XML), Resource Description Framework (RDF), Web Ontology Language (OWL), and SPARQL Protocol and RDF Query Language play an important role in solving problems in various domains, especially in managing and communicating data formats in a way that ensures semantic clarity (Patel and Jain, 2019). Therefore, Semantic Web technology retrieves meaningful information from search queries and displays search results relevant to users' interests (Głowacka et al., 2021; Mehta et al., 2015). It collects information with semantic consistency. An ontology defines how language is used to describe relevant content, including concepts, relationships, and properties assigned to the data (Gruber, 1993; Guarino et al., 2009), and can create a category or group of data with common characteristics. Properties represent characteristics or specific data related to classes, individuals represent individual sets of data in a class, and relations describe relationships between classes or individuals. Data are stored using RDF to describe various data in the form of graphs. Such a framework helps to store and search for data more efficiently, making them easier to understand (Patel and Jain, 2019).

This research aims to develop a Semantic Knowledge Base on the Semantic Web to facilitate undergraduate students at Nakhon Ratchasima Rajabhat University in efficiently discovering and learning up-to-date digital technologies. The compiled data are meticulously organized and interconnected, presented in an intuitive manner to enable users to readily access and apply the information. This eliminates the need for users to independently gather and comprehend data from diverse sources. Utilizing ontology techniques and the Hypertext Preprocessor (PHP), we developed a Semantic Web application that enables efficient data connection, search, and retrieval. The SPARQL Protocol and RDF Query Language, used for querying RDF data, allow us to precisely define and describe concepts, ensuring accurate and comprehensive information retrieval.

2. Purpose

This research on digital technology and learning in the 21st century consists of four steps:

1. Creating a conceptual framework for the development of an ontology,
2. Semantic web development,
3. Semantic web assessment, and
4. Effectiveness evaluation from users.

3. Related Documents and Research

3.1 Digital Technology and Learning in the 21st Century

In the article entitled *Digital Technologies, Innovation, and Skills: Emerging Trajectories and Challenges*, Ciarli et al. (2021) present the concept of using technology to create social and economic change. The researchers used the elements of this concept as components in their study, dividing them into three categories. Digital technology refers to the application of scientific knowledge to invent various tools and systems. Innovation refers to human efforts to improve and develop digital technology to make it more efficient. Digital skills refer to the ability to use digital technology to solve problems and perform tasks effectively.

3.2 Semantic Web

The development of Web 3.0, an extension of the Web 2.0 concept, focuses on creating and supporting online social networks. Users can connect, share content, and express opinions. However, Web 3.0 further extends this concept by managing large amounts of data using metadata to describe and organize web content more meaningfully. The Semantic Social Web (Web 2.5) serves as a bridge between Web 2.0 and Web 3.0 by combining essential characteristics from both to create the Semantic Web (Lin et al., 2024; Pileggi et al., 2012). The Semantic Web focuses on linking data and enabling systems to better understand the semantic dimensions of information. It aims to develop the web so that systems can understand the meaning of data and process it efficiently. This allows computers to interpret data semantically rather than merely reading it literally (Pauwels and McGlinn, 2022).

The need to develop the Semantic Web arises from the demand for systems that can link and search for information based on semantic meaning. The Semantic Web employs semantic technologies such as ontology to manage data and uses related tools and languages, including RDF (a framework for managing data in a relational graph format), OWL (a language for creating and using ontologies on the web), and SPARQL (a query language for retrieving semantic data from RDF databases). Additionally, the Hypertext Preprocessor (PHP), a popular scripting language used in web development, is utilized to coordinate interactions between users and servers. By integrating these technologies, the Semantic Web can efficiently connect complex data and support meaningful data retrieval (Colucci et al., 2024).

3.3 Ontology

Ontology is a concept representing a structured knowledge base or domain framework that helps organize and categorize knowledge for effective use. Creating an ontology requires a deep understanding of the domain under consideration. Ontologies are used in the Semantic Web to add meaning to web data, enabling searches and use based on semantic meaning and contextual relationships (Patel and Jain, 2019; Grimm et al., 2011). Ontology is created using a specific vocabulary that describes the properties and relationships of objects or entities within a domain. The knowledge content in a domain consists of *Concepts*, *Properties*, and *Attributes* that can clearly describe domain-related knowledge content (El-Gayar et al., 2019).

3.4 SPARQL

SPARQL, developed and standardized by the W3C, is considered one of the key components for developing the Semantic Web and Linked Data. It can be executed in various environments efficiently without the need for a dedicated server or browser. SPARQL's data storage and retrieval model has a clear structure and syntax, similar to the use of tags and attributes in XML for data manipulation. This allows for semantic storage and retrieval of data from RDF-based databases (Hogan, 2020).

3.5 PHP

PHP is an open-source programming language used for developing websites and web applications. It is designed to create dynamic websites that respond quickly to changes in data. In the context of the Semantic Web, PHP includes libraries that support integration with SPARQL for querying data from RDF databases based on RDF standards, facilitating efficient data connection and manipulation (Panchal and Chokshi, 2022).

4. Materials and Methods

This research employs the Semantic Web model to develop a Semantic Web framework for digital technology and learning in the 21st century using ontology techniques.

Fig. 1 illustrates the development and application of ontological techniques represented in the process of an ontology-based Semantic Web. The process is divided into three main phases: conceptual, physical, and Semantic Web, which categorize data and establish relationships among various elements related to digital technologies.

4.1 Creating a Conceptual Framework for the Development of an Ontology

The researchers reviewed relevant literature and research on digital technologies and learning in the 21st century. This information was used to develop a conceptual framework for classifying and organizing data to create an ontology. Important domains were defined, and classes, properties, attributes, axioms, and relationships were established to manage the data with an appropriate structure. The ontology was constructed using Protégé 5.0.

4.2 Semantic Web Development

The researchers designed the web interface and developed a SPARQL-connected web page. After determining the structure of the synthesized elements, the process proceeded to the physical stage by converting the data into OWL format and storing it in RDF format, organized as a data graph. The retrieved information was then displayed via a web page using PHP in connection with SPARQL for querying and retrieving data from RDF databases.

4.3 Semantic Web Assessment

This step evaluates the information retrieval system in terms of the correctness of its ontology design and its ability to link information relevant to the query. The target group for this step consisted of university experts with over five years of teaching experience, including two specialists in information systems and technology and one specialist in the Semantic Web.

The evaluation criteria used a rating scale based on the Likert guidelines (Srisa-ard, 2017), divided into five levels and interpreted using the average score ($\bar{x}$) and standard deviation (S.D.) as follows:

- 5.00–4.51 = Very good
- 4.50–3.51 = Good
- 3.50–2.51 = Fair
- 2.50–1.51 = Poor

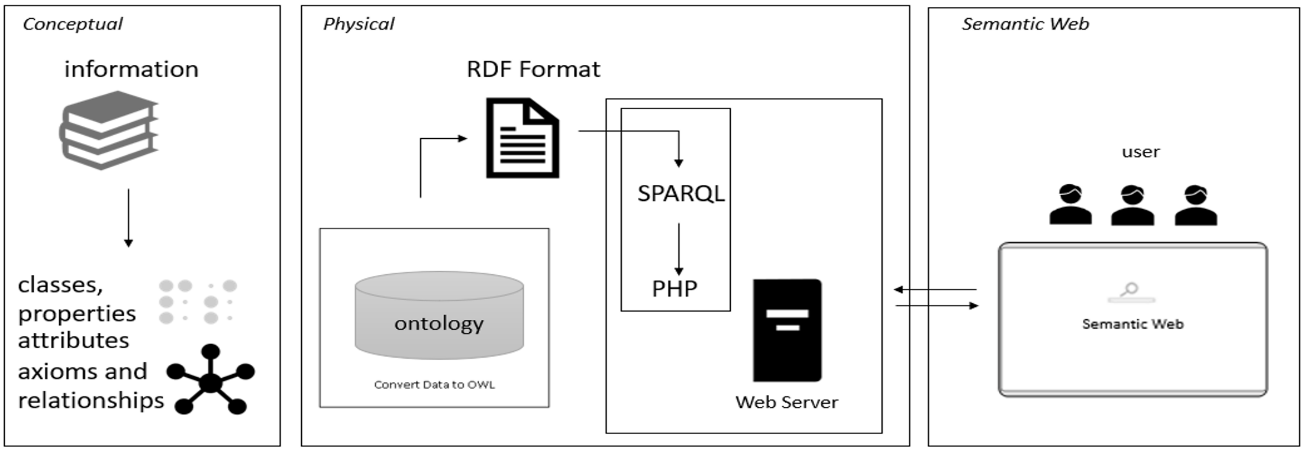

Figure 1. Semantic web model.

- 1.50–1.00 = Very poor

4.4 Studying the Effectiveness Evaluations Obtained from Users

This step presents the results of the ontological evaluation performed by the researchers. The aim was to assess the accuracy and precision of data extraction. The population consisted of 197 computer science students. The target group for this step, selected through step-by-step sampling, included 10 computer science students enrolled in a selective course titled *21st Century Technology and Skills*.

The results were statistically analyzed using performance indicators, including accuracy, recall, and F-measure. The researchers concluded and discussed the findings through statistical analysis of performance metrics to evaluate system performance (Anam et al., 2015).

$$\text{Precision} = \frac{TP}{TP + FP} \times 100\% \tag{1}$$

$$\text{Recall} = \frac{TP}{TP + FN} \times 100\% \tag{2}$$

$$\text{F-measure} = \frac{2 \times \text{Recall} \times \text{Precision}}{\text{Precision} + \text{Recall}} \tag{3}$$

5. Experimental Results

5.1 A Conceptual Framework for the Development of an Ontology

The researchers analyzed relevant documents and information sources and synthesized various elements based on ontology design. Three main classes and two subclasses were defined to represent relationships between different classes by employing four object properties to define relationships between main or subclass instances and four data type properties to associate instances with data.

The main classes related to digital technology and learning in the 21st century were classified based on the concepts of Ciarli et al. (2021), namely digital technology, innovation, and digital skills, as illustrated in Fig. 2.

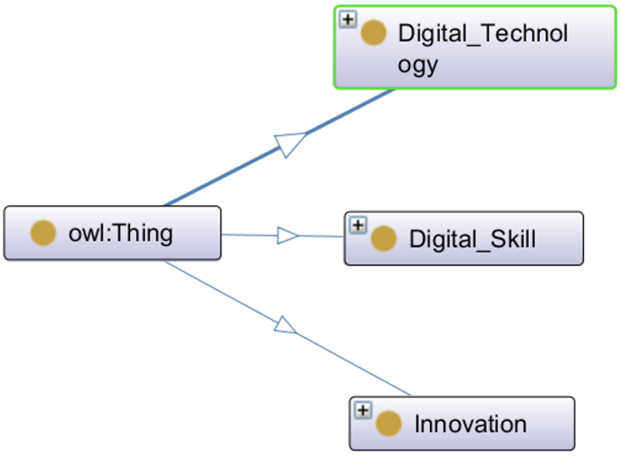

Figure 2. Classes and relationships of digital technology and learning in 21st-century learning.

After classifying the main classes, the researchers applied the concepts from International Telecommunication Union (ITU) (2021) concerning digital skills, which are divided into two subclasses. Additionally, the researchers studied information on digital technology from various sources. As a result, the *Digital Technology* class was divided into ten subclasses. The linkage of classes, subclasses, and properties within the ontology structure is shown in Table 1.

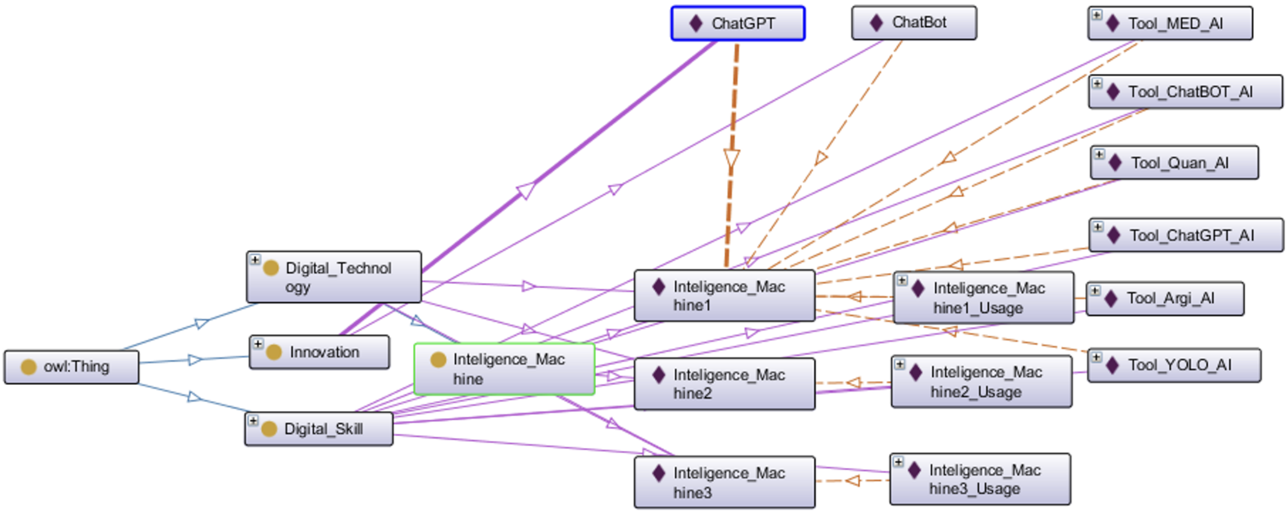

Figure 3. Example of relationships between instances of the class *Digital_Technology* and the subclass *Intelligence_Machine*.

Table 1. Linking of class, subclass, and properties.

Class	Subclass	Properties	
		Object	**Data Type**
Digital Technology	Big Data Analytics Cloud Computing Sensor Intelligence Machine 3D Printing Blockchain GIS Mobile Network Robotic Wireless	hasDigital	definitionOf
Innovation	–	hasTool	innovationOf
Digital Skill	usage tool	hasUse hasInnovation	usageOf toolOf

Table 1 presents the object properties used to specify relationships between classes and subclasses. Properties are divided into two parts for linking to instances, as follows:

1. **Object properties** used to specify relationships between classes and subclasses: (1) `hasDigital` links digital technologies with their relevant classes or subclasses; (2) `hasTool` identifies tools related to innovation or digital technology; (3) `hasUse` connects the usage of digital skills or digital technologies to relevant contexts; and (4) `hasInnovation` links digital technologies with innovations resulting from their use.

2. **Data type properties** associate specific data with instances: (1) `definitionOf` describes the meaning of digital technology; (2) `innovationOf` identifies innovations resulting from digital technology; (3) `usageOf` specifies the use of digital skills; and (4) `toolOf` identifies the tools associated with instances of digital technology.

From the above information, when searching for links to instances using the Semantic Web, the search for meaning in physical terms is performed for the *Digital Technology* class, linking it to subclasses, instances, properties, and definitions for each instance. Data type property conventions are used to assign specific information to each instance, as shown in Fig. 3.

As observed in Fig. 3, the relationships between object properties and instances of the class *Digital_Technology* and subclass *Intelligence_Machine* are used to define semantic relationships between classes or subclasses and instances, providing the meaning of instances such as *Chatbot* and *ChatGPT* through data type properties that associate instances with meaningful data.

5.2 Semantic Web Development

After the ontology development, the data were converted into the OWL format, a standard language that facilitates the identification and storage of semantic information. The data stored in OWL were then transformed into RDF format, which represents the relationships among entities, properties, and connections in a graph-based structure. This was achieved using PHP in conjunction with SPARQL to query and retrieve data from RDF databases, as illustrated in Fig. 4.

5.3 Semantic Web Assessment

The Semantic Web of digital technology and learning in the 21st century, developed using ontology techniques,

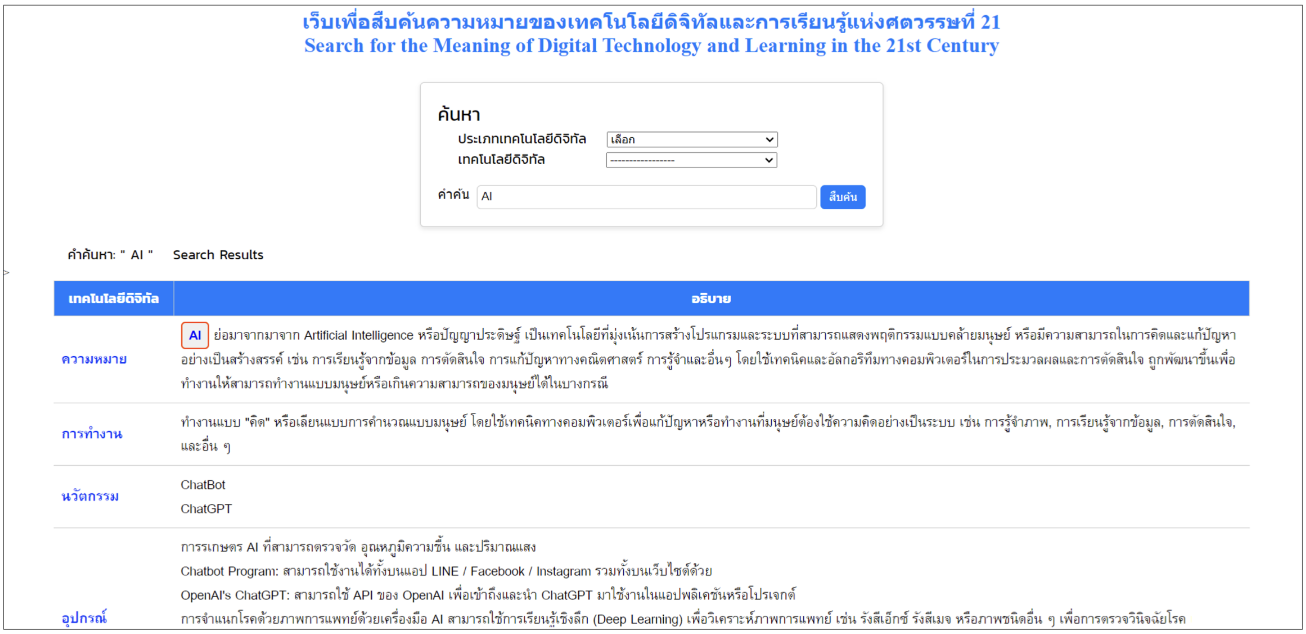

Figure 4. The semantic web of digital technology and learning in the 21st century with ontology techniques.

was assessed by three experts. The overall evaluation results were at a very good level ($\bar{x} = 4.52$, S.D. $= 0.19$). When divided into two categories—(1) Ontology and (2) Web development—the results were as follows:

1. **Ontology:** The design of the ontology structure, including the main and subcategories of the system, showed accurate and comprehensive relationships and was rated at a very good level ($\bar{x} = 4.80$, S.D. $= 0.45$).

2. **Web development:** The design of the Semantic Web for digital technology and learning in the 21st century was consistent with user needs and presented information in a clear and understandable format, also rated at a very good level ($\bar{x} = 4.60$, S.D. $= 0.55$).

5.4 Effectiveness Evaluations by Users

In this step, the information retrieval system was evaluated for the correctness of its ontology design and its ability to link information relevant to user queries. The aim of the ontological evaluation was to assess the accuracy and precision of data extraction, as illustrated in Fig. 5.

According to Fig. 5, users evaluated the system's effectiveness with the following results: precision at 96.25%, recall at 92.08%, and F-measure at 95.29%.

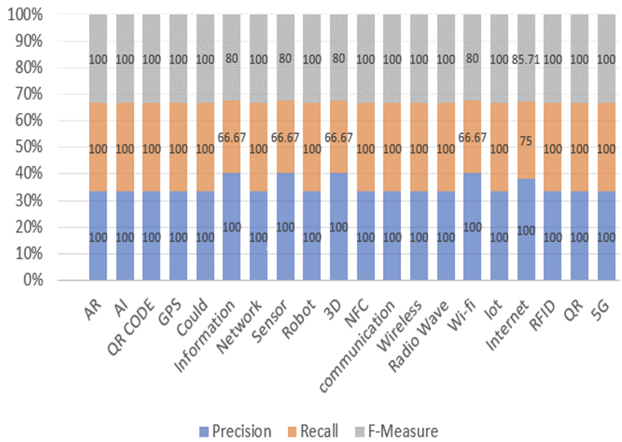

Figure 5. Effectiveness evaluations by users.

6. Discussion

Web development involves the exploration of the meaning of digital technology and learning in the 21st century using ontology techniques. It helps users discover and learn about digital technologies through innovations, applications, and tools that clearly illustrate relationships and link information and content. Semantic Web development for learning digital technologies in the 21st century using ontology techniques has the potential to support undergraduate education and enhance information retrieval efficiency. This is especially important in an era characterized by data diversity and complexity. The proposed system employs semantic language to aid understanding in digital technology education and learning, making it easier for undergraduate students to retrieve relevant content within a given context.

However, the limitation of the system is that it does not contain as much content as modern large-scale search engines. Compared to Google, the most widely used search engine, the proposed system remains limited in terms of data volume.

In addition, the development of the Semantic Web supports students' active learning by enhancing their skills through various learning strategies, such as blended learning, project-based learning, flipped classrooms, and problem-based learning. These strategies contribute to the development of communication, collaboration, creativity, and other essential skills. Their effectiveness depends largely on teachers' creativity and diversity in instructional design, which promotes meaningful learning experiences. Integrating these strategies with the Semantic Web framework can help learners gain deeper knowledge and understanding.

7. Conclusion

The researchers developed an ontology for 21st-century digital technology and learning, which consists of three main categories: digital technology, digital skills, and innovation. The classes and data were structured based on their meaning, usage, innovation, and associated tools, representing the key attributes of digital technology and supporting user learning through meaningful system interactions.

The researchers tested the system with ten undergraduate students majoring in computer education. Each student was assigned approximately five random keywords to search, resulting in a total of twenty input keywords, and all search results were recorded. The performance metrics demonstrated effectiveness, with precision at 96.25%, recall at 92.08%, and F-measure at 95.29%. This high level of performance indicates that the system was carefully developed based on a thorough needs analysis and a well-executed development process.

As a result, the system is suitable for academic use in learning management and can be applied to various teaching methods. This finding aligns with the work of Khabour et al. (2022), who explored Arabic sentiment analysis through a semantic approach. Their study demonstrated that semantic analysis is both challenging and effective in assessing opinions and emotions from Arabic texts—a language known for its complex structure compared to many Western languages. The semantic approach enables more detailed classification and interpretation of user opinions, leading to a deeper understanding of underlying sentiments. Their evaluation using a dataset from the hotel domain in Arabic achieved precision of 79.20% and an F-measure of 78.75%, indicating that the semantic approach yields better results than methods that overlook semantic meaning.

This conclusion also corresponds with the work of Chutney et al. (2014), who developed an ontology-based tourism recommendation system in Northeastern Thailand. Their goal was to improve the efficiency of tourism recommendation systems, addressing the issue that many existing systems lacked ontology-based structures to support effective information retrieval. Developing such an ontology is challenging due to the complexity of defining rules for organizing and retrieving data and understanding the associated syntax. Their ontology development employed top-down, bottom-up, and hybrid approaches to enhance retrieval efficiency. Experimental results showed that using the mixed-method design achieved an F-measure of 82.26%, demonstrating the system's effectiveness in delivering fast and accurate information retrieval that meets user needs.

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