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Ontology-based Interactive Learning Approach for Transdisciplinary Teaching in Learning Factories

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Abstract

Interactive learning provides a pedagogical approach to acquire skills and develop knowledge regarding transdisciplinary areas, especially in the burgeoning engineering sciences domain. In fact, learning factories have been shown to provide the appropriate environment for transdisciplinary teaching. Exposure to different knowledge domains is desired, but students face difficulties understanding complex foreign concepts over limited periods of time. As an example, the AllFactory at the University of Alberta is a unique facility that encompasses agricultural and biological sciences along with Industry 4.0 technologies. Aquaponics 4.0 mediates the growth of various plant and fish species while using engineering concepts to control the environment and ensure maximum quality control and high throughput. This paper proposes a digital interactive approach to present and teach complex foreign knowledge to students in time-constrained environments. A graphical user interface is designed to provide a step-by-step guide on developing the hydroponic and aquaculture component to investigate Aquaponics 4.0 systems, where all the required knowledge is extracted from a predefined ontology model.

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1. Introduction

Learning factories have been for the past decades pushing for a more transdisciplinary nature of engineering education, training, and research, and thus bridging the gap between advanced manufacturing technologies and engineering teaching methods [1]. This transformation to engineering pedagogy has required changes in didactical models, such as a more visual and experiential approach to learning, that could help students handle the challenges of transdisciplinary concepts and processes [2]. In fact, exposing students to other disciplines is important to experience differences in thinking and problem-solving approaches. To successfully create a transdisciplinary learning environment, teachers require additional resources to present novel foreign concepts and additional time to ensure students' understanding of these concepts [3]. However, typical classroom or practical sessions are time-constrained environments where most students race against the clock to finish their learning goals. As such, research has focused on improving transdisciplinary educational models and creating more pedagogical tools that ease the introduction of other disciplines while reducing the time required for it. Digital learning methods, such as gamified interactive platforms, have supported those goals and, with the recent pandemic, institutions have accelerated the introduction of digital learning.

Following digital learning trends, this paper presents the use of an interactive learning approach to improve students' experience in transdisciplinary learning. In this case, the use of an ontology model that stores the relevant

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foreign knowledge and is continuously accessed by the user through the interactive platform is researched. Offering interoperability of information across domains, ontology is defined as an explicit and formal specification of a conceptualization [4], [5] This approach aims to visually present the desired knowledge to the students in an open and exploratory manner, improving student experience and increasing the effectiveness of classroom time. The transdisciplinary environment used for the interactive platform is based on the AllFactory situated at the University of Alberta, Canada; which focuses on advanced digital manufacturing processes applied to vertical farming, a novel sustainable indoor agricultural method [6][7].

The remaining sections of the paper present the methodology used to develop and validate the proposed approach, then provide an overview of the interactive platform developed, and finally some results that validate the approach as an improvement over the current more traditional paper-based method.

2. Methodology

The methodology followed to develop the proposed interactive learning platform for aquaponics 4.0 learning factory environment is shown in Fig. 1. First, a predefined ontology model *″AquaONT″* is populated with relevant system knowledge [8]. The information stored is extracted from the system continuously, from sensors for example, and from experts' knowledge. Then, the existing and inferred knowledge is extracted from the ontology model using SPARQL queries on Apache Jena API [9]. The results from SPARQL queries are saved in *.csv* format, making it convenient to access the ontology knowledge across various platforms. MATLAB app designer module is employed to develop a graphical user interface (GUI). Finally, the .csv file is imported in GUI and a set of governing equations are developed to obtain useful information for transdisciplinary learning and aquaponic 4.0 system's development [10].

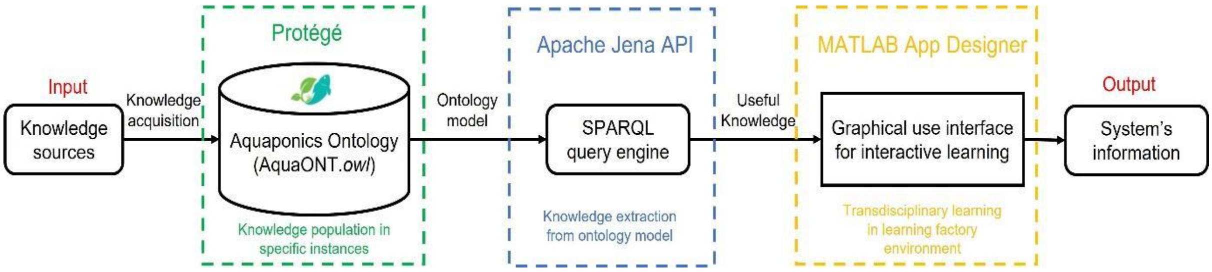

Fig. 1. Methodology to develop interactive learning platform for aquaponic 4.0 learning factory setup

To validate the proposed method, anonymous engineering students with no prior knowledge of the platform, with no knowledge of aquaponics or biological sciences, and with no connection to the learning factory volunteered to assess its viability. Also, a formative assessment is designed consisting of a performance rating scale [11] that enables students to provide feedback on the learning methods tested. This methodology has been found successful when requesting student feedback and validating novel teaching methods recently [12].

3. Platform development

The Aquaponics 4.0 virtual learning platform provides a digital interactive learning approach to present and teach concepts related to a smart aquaponics system. Knowledge from the ontology model is retrieved using SPARQL query engine and is represented using a graphical user interface (GUI). This GUI is designed using the MATLAB app designer tool and allows the user to make choices that eventually impact the model performance. By enabling environment modification based on user behavior, a direct relationship between "decision" and "information feedback" is established, known as the "Single-loop learning" process [13]. Such information empowers the learner's comprehension of the system, as his/her decisions can converge the physical world with the intended objective [14].

The GUI consists of six tabs, each capturing data from the ontology model and enhancing the user's learning experience. These tabs have been labeled as: 1) Aquaponics Overview, 2) Hydroponic Design, 3) Aquaculture

Design, 4) AllFactory System, 5) Smart Sensors, and 6) Model Performance. A brief overview of each of these tabs is provided in Fig. 2.

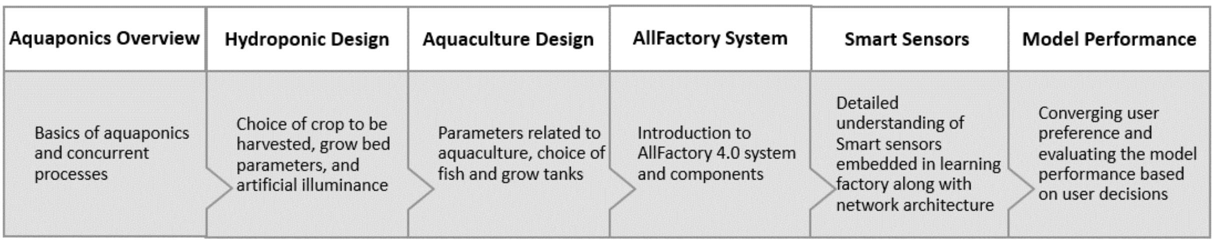

Fig. 2. Aquaponics 4.0 virtual learning platform app overview

Explaining complex foreign knowledge to students in a time-constrained manner can prove to be challenging. Offering high potential for display and innovation transfer, the proposed interactive learning approach guides the user through the basics of the knowledge being imparted [15] while allowing free exploration of all the accessible content. To achieve this objective, the GUI app starts with the aquaponics overview tab that expedites this process. Providing a holistic view of the aquaponics system, this tab introduces the user to major components and concurrent processes through a comprehensible illustration.

The hydroponic component acts as the nerve center and regulates the aquaponic system. The second tab (Fig. 3) introduces the user to the hydroponic design, enabling them to choose all the elements that formulate the system: from the crop species, grow bed type and number to the artificial illumination source that provides the photosynthetically active photons for crop growth. This is followed by the aquaculture design tab, whereby the user can select amongst the various species of fish as well as the fish grow tanks. Each choice made by the user populates data related to that particular entity from the ontology model, enhancing the user's comprehension of

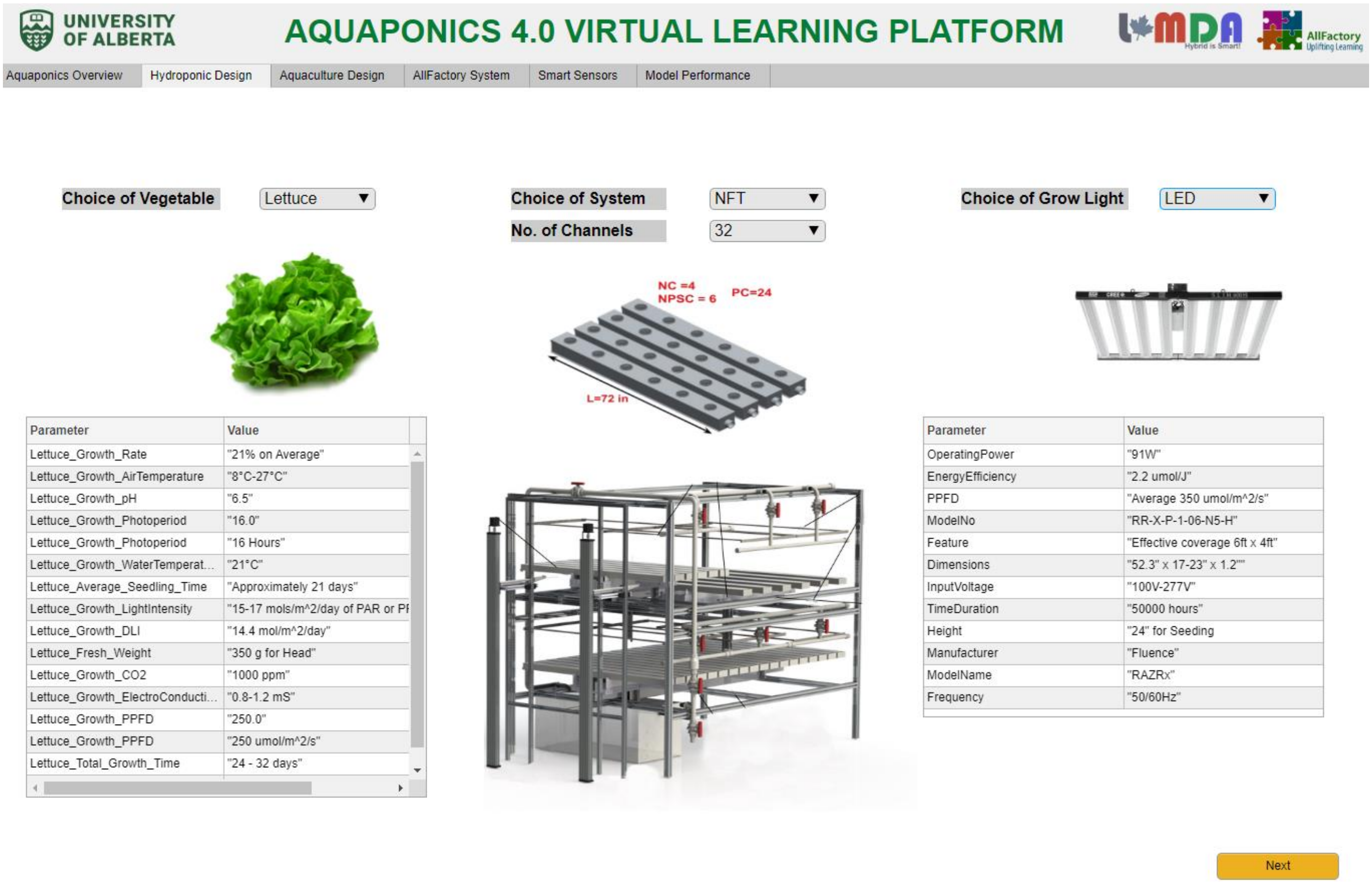

Fig. 3. Illustration of Aquaponics 4.0 Virtual Learning Platform Hydroponic Design tab

the system, and providing a brief text containing information regarding the choices made and its impact on system performance.

The AllFactory and smart sensor tabs represent the physical system present in the learning factory. Encouraging the users to hover through the interactive illustrations, these tabs show detailed information about the various smart sensors embedded in the learning factory that gather real-time data to enable smart decision making. Furthermore, users are familiarized with the current system architecture used for data storage and retrieval. Finally, the model performance tab converges all user choices and displays the impact of those decisions on the aquaponics system. Main parameters such as system performance, harvest intervals for crops and fish, or energy consumption are highlighted in this tab, allowing the users to understand the outcome of their decisions.

4. Results

Finally, the platform is to be validated using a formative assessment. This assessment is customized with core parameters to fit the learner population specific to the learning factory use. These parameters have been listed in Table 1. Standard statements are generated for each of these parameters by using a narrative process, with scores ranging from 1 to 5 (1 being the lowest rating and 5 the highest). Students are then asked to rate each of the parameters based on their level of understanding and experience.

Table 1. Core parameters to evaluate interactive learning platform

No.	Parameter	1	2	3	4	5
1	Clarity	Complex	Fairly Complex	Average	Fairly Simple	Simple
2	Time Management	Onerous	Fairly Exhausting	Average	Fairly Swift	Swift
3	Practicality	Abstract	Fairly Abstract	Average	Fairly Practical	Practical
4	Effectiveness	Ineffective	Fairly Ineffective	Average	Fairly Effective	Effective
5	Relatable	Unrelated	Fairly Unrelated	Average	Fairly Related	Related
6	User Guided	Wandering	Fairly Wandering	Average	Fairly Guided	User Guided

The result of the formative assessment is plotted using a radar graph which provides a virtual representation of learning performance [16]. This radar graph is broken into six core parameters as listed before. The results from both traditional as well as interactive learning approaches are overlaid on the same graph, enabling a head on comparison.

For this study, an experiment is conducted involving 20 participants. Participants are asked to go through the AllFactory 4.0 user manual, currently in use for teaching purposes in the learning factory, followed by an initial assessment questionnaire. Then, the Aquaponics 4.0 virtual learning platform is introduced, and participants are requested to fill the assessment questionnaire once again. By comparing the students' assessment of both methods, insight on the impact of the change of platform is gained. The results from the two assessments are presented in Table 2, and plotted on the radar graph, illustrated in Fig. 4.

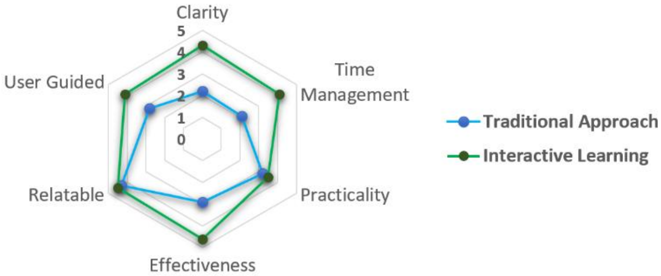

Fig. 4. Radar graph comparing traditional vs interactive learning approach

Table 2. Results from case study highlighting min, max, standard deviation and variance of the recorded data

Parameter	Minimum		Maximum		Standard Deviation		Variance	
	Traditional	Interactive	Traditional	Interactive	Traditional	Interactive	Traditional	Interactive
Clarity	1	4	3	5	0.60	0.46	0.36	0.21
Time Management	1	4	3	5	0.54	0.30	0.29	0.09
Practicality	3	3	4	4	0.40	0.50	0.16	0.25
Effectiveness	2	3	4	5	0.70	0.66	0.49	0.44
Relatable	3	3	5	5	0.64	0.67	0.41	0.45
User Guided	2	3	4	5	0.75	0.54	0.56	0.29

Survey results provide an insight on the learning efficacy of the two approaches, with interactive learning securing higher rating in almost all core parameters. Though “practicality” and “relatability” parameters are rated quite similar in both the approaches, interactive learning excels in making the transdisciplinary teaching simple, swift, effective and user friendly.

5. Future Work

An interactive graphical user interface allows for an expeditious transfer of transdisciplinary knowledge among learners. The platform obtains relationships between different classes using a predefined ontology model, AquaONT. While this facilitates interactive teaching in a learning factory environment, it does not dispense the real-time status of various components and subsystems within the learning factory. Involving concrete realization of physical entities in virtual environment, digital twins modulate and optimize the learning factory using digital copy of physical systems [17]. Future work includes integrating real-time monitoring and control with interactive learning platforms using intelligent sensors, digital twins, and the Internet of Things (IoT), enhancing the user learning experience.

6. Conclusions

Providing a knowledge based interactive learning approach to present and teach complex foreign knowledge to students in a time-constrained environment, this paper proposes an interactive graphical user interface (GUI) designed using MATLAB app designer tool. The GUI extracts knowledge from an ontology model, AquaONT, and enables environment modification based on user behavior. The model establishes a direct relationship between decision and information feedback, empowering the learner's comprehension of the system. A head-on comparison of traditional versus interactive approach is performed in the case study, reveling the positive impact of interactive GUI on the transdisciplinary learning.

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