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Attaining Learning Objectives by Ontological Reasoning using Digital Twins

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Abstract

Learning Factories provide a propitious learning environment for nurturing production related competencies. However, several problems continue to plague their widespread adoption. This study mentions these issues before proposing the use of digital twins as an alternative. The study presents an approach towards modelling such a digital twin and proposes a solution that uses ontologies to develop a formal representation of the domain (a flexible manufacturing system) and the learning that occurs in the environment. A reasoning mechanism is used deduce inferences from the ontology to facilitate automated assessment of the learner. A use-case for the pedagogic digital twin is presented and discussed before proposing future directions for work.

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Keywords: Digital Twin; Learning Outcomes; ontology; Reasoning; Web Ontology Language (OWL); Learning; Pedagogy

1. Introduction

With the arrival of the fourth industrial revolution, what is better known as Industry 4.0, the manufacturing sector has seen a holistic shift from conventional automated systems to one that is driven by Internet of Things (IoT) and cloud computing involving cyber physical systems. This has resulted in a shift from traditional teaching methods to one that is more hands-on. One approach addressing this shift has been the development of learning factories. A learning factory is a facility that realizes a process or product in an academic setting for the purpose of training and educating students [1], normally in or in close proximity to the campus premises. They are set up with the intention to inspire action-oriented experiential learning [2].

Some of the limitations of the learning factories were identified as follows [1] [3] [4] : (1) limited mapping ability for challenges prevalent in academia and industry as learning factories generally focus on particular aspects of manufacturing, (2) space and cost related issues when it comes to mapping the different factory levels, (3) fixed locations of learning factories mean limited mobility, (4) evaluation of production related competencies after the learning experi-

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ence. This is where digital twins can prove to be advantageous. The digital twin can be used to map the entire factory floor and its existing levels while the physical setup may consist of that of value in the academic setting.
This paper investigates how digital twins may be leveraged to assist the learning process of manufacturing systems. This necessitates the extension of conventional digital twins to suit the pedagogic context and involves representation of the learning objectives which guides the student to the set task. Such a didactic transformation should also have the ability to compare performance of different students. Hence we define the following research questions: How do we model learning outcomes in the context of Digital Twins? How do we evaluate the performance of students? How do we guide a student towards the desired level of skills with respect to his or her current status?

2. Definition of key terminologies

The education agendas of today's higher universities are moving towards an outcome-based approach towards implementing courses and two terms are often conflated in literature, learning objectives and outcomes.

Learning Objectives: Learning objectives are course-level statements describing what the course participant is in-tended to be able to do upon completion of the course. They are generally less broad than the learning goals of the course.
The ABCD model [5] is one of many guides that ensures a learning objective is on point. It consists of four components: (1) Audience: who the learning is intended for. (2) Behaviour: what behaviour is expected from the learner in response to the learning that has occurred usually described using action verbs such as "identify", "demonstrate", etc. (3) Condition: the circumstances under which the learner will be able to exhibit the behaviour (4) Degree: the level of mastery or expected performance by which the outcomes may be judged.

Learning Outcomes: The specificity increases with learning outcomes and it is an explicit statement that describes what a course participant will have achieved and demonstrate at the end of the course. They are specific, demonstrable (measurable) and student-centered. Learning taxonomies are often used to classify learning outcomes that help in identifying the extent to which its associated skills or knowledge has been attained. Several such taxonomies are proposed in literature but we use the SOLO taxonomy in this paper. SOLO is an acronym for the **S**tructure of the **O**bserved **L**earning **O**utcome and is a method of classification of the learning outcomes of a learner based on his/her depth of understanding. [6]

Assessment: Assessments are strategies or techniques to determine the extent to which the student demonstrates learning outcomes aligned towards the course objectives.

Course Alignment: Alignment of courses is the process of mapping of the learning activities, learning outcomes and the assessment. Assessment validates the learning outcomes against the learning objectives and presents the instructors with evidence of how well the student has learnt what the course intend them to learn. Hence, it is necessary to align the assessments with the objectives.

3. Approach

This section presents the approach taken towards developing a digital twin with pedagogic extensions for a production based engineering course.

3.1. Envisage and Envision

This stage involved researching the aptness of Digital Twin in the educational set up by examining the experience it brings to the students. A didactic framework centred on digital twins was first established using a pedagogically sound theory [7] before instantiating different classes of learning theories in it [8]. This stage also saw establishing of the learning outcome as *"To understand the basics of production activity, key manufacturing techniques and operating*

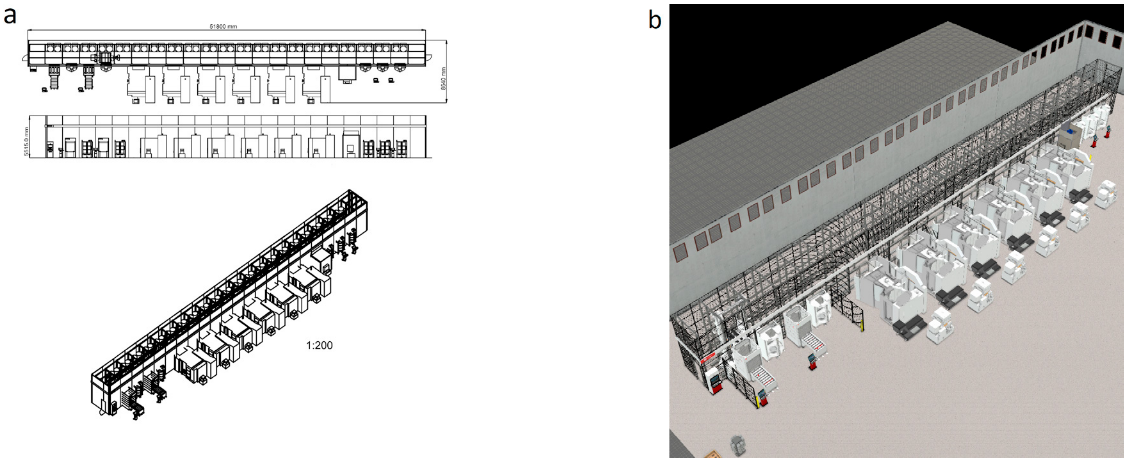

Fig. 1. (a) Identification of the Process; (b) Scaled Twin.

models in the Finnish industry." This stage, while laying the foundations of the research also gave the green signal to pursue solutions to the posed research questions.

3.2. *Identification of the Process and Course Activities*

This stage involved finding out the right processes and configuration that would help in accomplishing the course objectives. The manufacturing process chosen was that of a flexible manufacturing (FM) system and understanding its principles were the objectives. The configuration of the layout was ascertained taking into account the important industrial processes prevalent in the industry whilst keeping in line with the learning objectives. The layout (Fig. 1a) consisted of an Automated Storage and Retrieval System that included an automated storage and retrieval system, 5 Loading Stations, 6 Machining Centers and 2 Material Stations.

The course was set to follow the didactic framework envisioned in the earlier stage [7] . Lectures were planned to introduce the course to the student while explaining theoretical concepts underpinning FM systems. The digital twin is introduced here and is next followed by an online quiz which on successful completion creates an initial hypothesis. Building on the decided learning outcomes of the course, to be able to "understand the manufacturing techniques" it was deemed necessary by the course personnel that the students themselves be able to manufacture custom parts as per requirements posed by the them. This was to take place during the next part of the didactic framework in the laboratory where the students were to focus mostly on creating fixtures, a part, install the fixtures on a pallet and then make an order in the user-interface. At the next stage, an exercise at the Training Center is planned where the students will manufacture and complete the order they made in the laboratory.

3.3. *Model Domain Knowledge and Pedagogic Extensions*

As mentioned in the Introduction, any digital twin of pedagogic value needs to have didactic transformations that justifies its pedagogical context of usage. Such transformations, as mentioned earlier, needs to have a description of the learning objectives. Further, any pedagogic tool would be incomplete without assessing and evaluation of the learning outcomes.
The authors have chosen ontologies to model domain information for the following reasons. (1) Taxonomic reasoning was fundamental in deciding with ontologies due to their ability for semantic modelling of concepts. With the ability to use classes, properties, instances, aggregation and generalization relations, ontologies were deemed more suitable as opposed to databases that focus on data storage and prove challenging to represent manufacturing domain knowledge. (2) The Open World Assumption (OWA) by ontologies would prove useful in times when modelling the knowledge

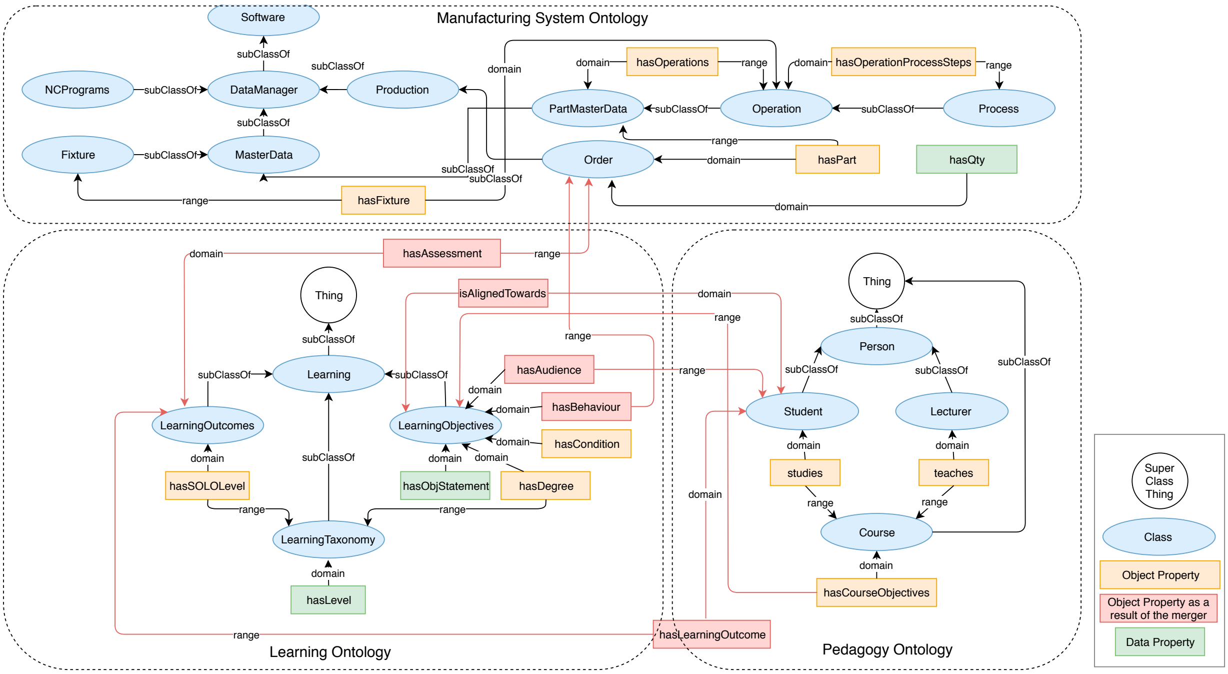

Fig. 2. Ontology Schema.

acquired by the students. (4) Future developments on works presented in this paper can be made with the ontology developed in this study.

3.4. Pilot a Twin

A pilot twin is next developed consisting of a component of each type (Crane, Storage, Machining Centre, Washing Machine and Loading and Material Stations). During the development of the twin, a modular approach was followed as part of a vision of the digital twin to be able to adapt to various layout configurations as part of future work. The Pilot twin is deployed and what followed the deployment is a number optimizations in performance parameters tuning to get it to the desired state. This deployment serves mainly two purposes: (1) Checking how the deployment has supported the goals identified as a part of the envision and modelling stages is analysed. (2) The deployment of the pilot twin also serves as a midway point in implementing the functional logic in the creation of the digital twin. Since the next step would be to scale twin to encompass the complete layout any anomalies present would be duplicated and it would be appropriate to rectify any present at this stage.

3.5. Scale the Twin and Monitor and Measure

The digital twin is scaled to encompass the entire layout (Fig. 1b) . The modular approach to developing the pilot twin meant that this stage involved only duplicating existing components with minor revisions. The completed model is deployed and key insights on learning are measured.

4. Implementation

4.1. Ontology Modelling

The ontology developed comprises of three main artefacts as a sub class of the general class *Thing*; the manufacturing system, the pedagogical elements and the learning that occurs as a result of pedagogy (Fig. 2).

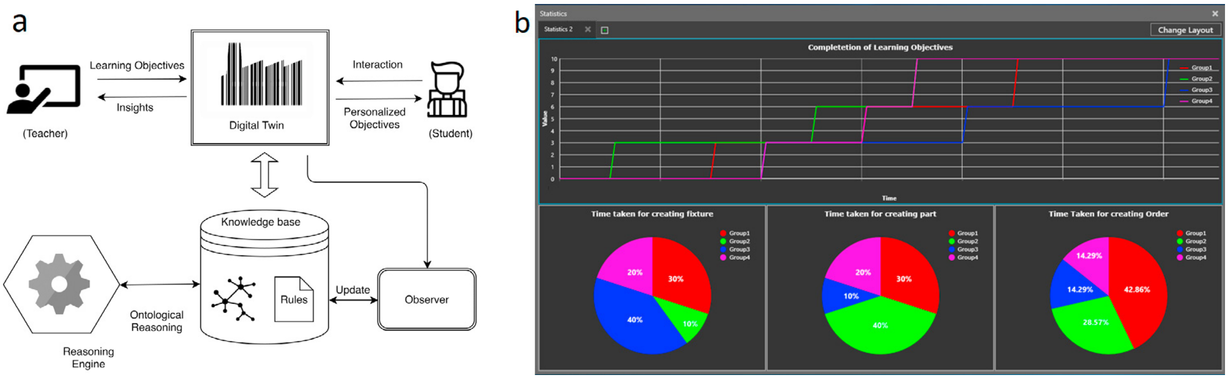

Fig. 3. (a) Architecture; (b) Insights.

The Manufacturing System Ontology is modelled using ontologies as shown in Fig. 2 although only those domain information relevant to the context of the learning use case due to paucity of space. The structure underlying the ontology is that the *Order* class has one or more orders (instances of class *Order*) that contain a part. Each part is manufactured by one or more operations (instances of class *Operation*). These operations further are materialized by a sequence of process steps (instances of class *Process*) that include a combination of loading, machining, washing, manual and unloading steps.

The Learning Ontology (super class *Learning*) comprises of the learning outcomes, learning objectives and the learning taxonomy whose theoretical aspects have been covered in Section 2.

The *LearningObjectives* class represents the ABCD model and hence has 4 properties while the *LearningTaxonomy* Class represents the SOLO Taxonomy and has 5 properties.

The LearningOutcomes Class represents the outcome of learning and is modelled to have two properties, *hasAssessment* and *hasSOLOLevel*.

The Pedagogy Ontology: The pedagogy ontology consists of Class *Person* and Class *Course*. The *Person* Class constitutes of sub-Class *Teacher* that *teaches* (object property) a *Course* and a sub-Class *Student* that *studies* (object property) the *Course*.

4.1.1. Manufacturing, Learning, Pedagogy: The Combined Ontology and Course Alignment

The combined ontology is a merger of the above three ontologies representing the manufacturing system, pedagogy and the learning that occurs within the domain. The main outcome of this merger is the alignment of the course, and by doing so making sure that the course objectives are in harmony with the learning activities and the assessment.

This merger makes way for a few associations. These associations are marked in red. A student that takes the course *hasLearningOutcome* (object property) of Class *LearningOutcome*. The course *hasCourseObjectives* (object property) of Class LearningObjectives which inturn hasAudience as the student. The LearningObjectives Class also has an object property *hasBehaviour* that for the current use case is modelled as Class *Order*. Class *Order* is also modelled as the learning outcome that has *hasAssessment* which in the context of this use case is the Order *Class* of the Manufacturing Management System.

4.2. System Architecture

The system consists of the Digital Twin that interacts with its users (both students and teachers), a knowledge base that consists of the domain ontology and its associated rules that are coded as a python script and resides in the digital twin or maybe expressed in Semantic Web Rule Language (SWRL) (Fig. 3a). Due to paucity of space, only a couple of rules are shown in Table 1. A reasoner engine uses these rules to assess the learning outcome of the student against the set learning objectives and constantly evaluates the progress of the student towards the set objectives. The Observer (not implemented in the use case) is the module responsible for capturing additional information that pertains to the user behaviour and thereafter updates the learner's profile. This could be anything from mouse-tracking, eye-tracking or any other metrics on the navigation of the user on the digital twin such as temporal and behavioural aspects.

Table 1. SWRL Rules

Rule No.	Rule
1	IF (x ***is-a*** Student) AND (x ***hasLearningOutcome*** x_LOut1) AND (x ***isAlignedtowards*** x_Lobj1) AND (L_Obj1 ***hasDegree*** x_deg) AND L_Out1 ***sameAs*** L_Obj1 -> x ***hasSOLOLevel*** x_Deg
2	IF (x ***is-a*** Student) AND (x ***isAlignedTowards*** x_LObj1) AND (Lobj1 ***hasRequiredSOLOPoints*** r) AND (x ***hasSOLOpoints*** n) AND (n ***lessThan*** r) AND (x_Lobj1 ***hasPrevious*** x_Lobj0) -> x ***hasLearningObjectives*** xLobj0

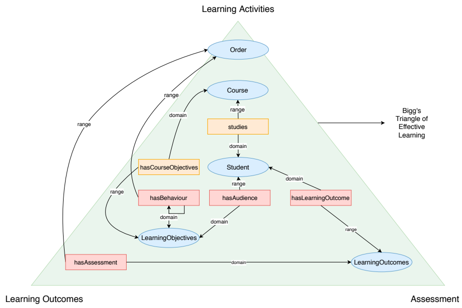

Fig. 4. Instantiation of Bigg’s Triangle of Effective Learning in Ontology.

5. Use Case

One intended learning outcome that is aligned towards the course objective defined would read *“At the end of the course, the student will be (1) competent in navigating through the user interfaces of FM systems, manage production requirements and gain key insights”* with a maximum SOLO points of 10).

This SOLO points of 10 is attained in 2 parts, the quiz after the lectures is an activity that is of SOLO Level 2 and the laboratory exercise that is of SOLO Level 3. It is important here not to confuse SOLO level with SOLO points. SOLO points are accumulated over time as tasks are completed and the SOLO Levels are calculated as a weighted average of the SOLO points to map the student to the overall SOLO Level at the end of the course. For the laboratory exercise, the teacher inputs the order requirements for each students via an excel form generated by the digital twin. The digital twin populates the ontology with the order information as the behaviour of the learning objectives with the corresponding student as the audience. The order as modelled earlier contains parts, each of which contains a set of operations and its entailed processes that make the operation. Each of these tasks contains assigned SOLO points that the student will have attained have they executed correct tasks on the digital twin. Successful completion of both activities would result in the attainment of 10 SOLO points. Simple rules such as those documented in Table 1 infers necessary axioms in the ontology by the reasoner.

6. Discussion

The ontological model developed in Section 4.1 essentially models the expected student behaviour (the intended learning objective) in our use case as the Order placed by the student in the manufacturing system. This is represented by the *hasBehaviour* object property of Class *LearningObjectives* and is populated by the digital twin based on the input from the course personnel. The *LearningOutcome* Class consists of the actual Order placed by the student in the digital twin and *hasAssessment* as the same class as the behaviour of the learning objective. Conceptually this means to say that the behaviour of the student is assessed to check its alignment with the objectives of the course thus enforcing course alignment. Such a method may be used any behaviour of the student that can be modelled and assessed using ontologies. If we examine the structure of the ontology schema Fig. 2, we see that it conforms to Bigg’s triangle of effective learning (Fig. 4). Such an instantiation leads the author to believe that the underlying schema is effectively modelled to represent learning objectives and outcomes and more importantly align the assessment towards set objectives. The effectiveness is further accentuated by the fact additional intended behaviours of the student can be modelled as classes and attributed to students using the *hasBehaviour* object property of the *LearningObjectives* Class, while the actual behaviour of the student, which obviously is modelled by the same class as the intended behaviour, can be attributed to the student by the *hasLearningOutcome* object property of the *LearningOutcome* Class. This means to say any behaviour that can be modelled using ontologies can be instantiated and checked via the ontological reasoning mechanism used in this study.

In the use-case, the students all begin at the bottom with the assumption that students have no prior knowledge regarding the subject, SOLO level 1, i.e. the pre-structural level, where the student has not grasped the concepts and has scattered information regarding the subject and have no SOLO points. Upon assessment of aligned course activities the overall SOLO level of the student advances. After the lectures, SOLO points are assigned depending on the their performance in the online quiz. These are stored in individual student profiles in the knowledge base. The exercise in the laboratory extends on the SOLO Levels attained in earlier pedagogic steps. We define progression in the SOLO levels as attainment of competence as did John Biggs that led to the proposed taxonomy in his work [6]. (Fig.3b) shows the demo data of performance of 4 students. We see that as the student progresses with the creation of the order, the SOLO points assigned to the sub-tasks are accumulated by the respective student. The student may not end up with the maximum SOLO points as an indication of not achieving the intended learning objectives due to his/her performance if the digital twin observes any divergence from the set learning objectives. Thus the SOLO levels of various students may be compared as shown in (Fig. 3b).

Based on the real-time insights the digital twin is able to guide the student based on the student's current status. For example, if the time taken for doing certain operations passes beyond a threshold set by the course personnel, learner and further task specific assistance may be provided based on the learner profile and SOLO level.

7. Conclusion and Future Work

The work presented in this paper uses established theories to model learning outcomes, objectives and assessment in a pedagogic context of manufacturing systems.The underlying schema takes into account the learner's profile focuses on competency attainment through reasoning of behavioural assessment of aligned learning outcomes. Further, the ontology can be easily extended to assess any behaviour that can represented using ontologies.
An active development is the integration of Virtual Reality with the digital twin to further augment the learning experience. The students are expected to leverage VR technology carry interact with the model real time.

References

[1] E. Abele, G. Chryssolouris, W. Sihn, J. Metternich, H. ElMaraghy, G. Seliger, G. Sivard, W. ElMaraghy, V. Hummel, M. Tisch, et al., Learning factories for future oriented research and education in manufacturing, CIRP annals 66 (2) (2017) 803–826 (2017).

[2] J. S. Lamancusa, J. L. Zayas, A. L. Soyster, L. Morell, J. Jorgensen, 2006 bernard m. gordon prize lecture*: The learning factory: Industry-partnered active learning, Journal of engineering education 97 (1) (2008) 5–11 (2008).

[3] M. H. M. I. Hamid, M. Masrom, K. R. Salim, Review of learning models for production based education training in technical education, in: 2014 International Conference on Teaching and Learning in Computing and Engineering (LaTiCE), IEEE, 2014, pp. 206–211 (2014).

[4] M. Tisch, C. Hertle, J. Cachay, E. Abele, J. Metternich, R. Tenberg, A systematic approach on developing action-oriented, competency-based learning factories, Procedia CIRP 7 (2013) 580–585 (2013).

[5] I. Robert, et al., Instructional media and technologies for learning, 7TH Ed., 2002 (2002).

[6] J. B. Biggs, K. F. Collis, Evaluation the quality of learning: the SOLO taxonomy (structure of the observed learning outcome), Academic Press, 1982 (1982).

[7] J. David, A. Lobov, M. Lanz, Leveraging digital twins for assisted learning of flexible manufacturing systems, in: 2018 IEEE 16th International Conference on Industrial Informatics (INDIN), IEEE, 2018, pp. 529–535 (2018).

[8] J. David, A. Lobov, M. Lanz, Learning experiences involving digital twins, in: 2018 IEEE 16th International Conference on Industrial Informatics (INDIN), IEEE, 2018, pp. 529–535 (2018).