A Classroom Activity Ontology and Knowledge-Based Assessment Approach

Gina Martinez, Osama Abuomar, Jason Perry, Kasey Kane
Department of Engineering, Computing and Mathematical Sciences
Lewis University, Romeoville, IL
{martingi, oabuomar, perryjn, kaseytkane}@lewisu.edu

***Abstract*— This Innovative Practice Full Paper presents a novel approach for assessing socio-technical learning objectives – learning objectives that include social-impact skills and professional technical competencies of engineering students. Socio-technical learning objectives in engineering courses, such as the ability to make ethically informed judgments and the ability to respectfully interact with teammates, are challenging to assess for many reasons, among them being that their assessment can be time consuming to administer and can be subjective. In this paper, a knowledge-based assessment framework is introduced, which includes a Class Activity ontology that describes classroom entities and events, and a query framework that unambiguously specifies student actions, sequences of actions, and interactions (assessment scenarios) to be assessed. By specifying the assessment scenarios in a precise way, the subjectivity of the process is reduced or removed. Moreover, this can be used as a tool for the education community to prescribe or recommend assessment scenarios, which, prior to our work, could only be specified in a narrative way. The approach can significantly reduce the time required to set up and administer assessments for socio-technical learning objectives, which traditionally may use portfolios, practical exams or case study analysis and evaluation.**

The proposed ontology model and knowledge-based assessment framework is designed to be extendable so that new course content, modality and activities can be supported. This ontology-based approach is able to support new queries to accommodate the inherent heterogeneity of what student behaviors and actions instructors believe to demonstrate a specific skill or trait. Furthermore, this approach allows for a "plug-and-play" method of disseminating assessment recommendations and guidelines. Therefore, our knowledge-based assessment framework provides standardization while retaining flexibility.

Keywords—assessment, ontology, socio-technical, professional engineering skills, semantic, knowledge-based

I. Introduction

The engineering profession, and thus the preparation needed to assume the role, has experienced significant diffusion and broadening in the last few decades, even more so in the last few years [1], which can be attributed to technology becoming widely and deeply embedded in every facet of modern society [2]. This broadening of the desired engineering skillset encompasses both technical knowledge and skills, as well as social competencies and characteristics. Modern engineers need to have technical mastery of their specific fields as well as proficiency in other skills that significantly impact their professional performance and the solutions they produce. For example, business and communication skills are among the "soft skills" practicing engineers often wish were emphasized more in their formal undergraduate education [3]. These skills may also be referred to as professional or social impact skills in much of engineering education literature. In this work, we refer to these skills collectively as "socio-technical" since we wish to encompass soft and social-impact skills, as well as behaviors and attitudes that demonstrate engineering competencies, such as the ability to make ethically informed judgments, problem solving, and an ingrained observance of safety procedures.

Unfortunately, these characteristics are generally difficult to assess in a classroom [4]. Studies have shown that students often struggle with these learning objectives and instructors find them challenging to teach and assess. On the other hand, engineering program accreditation bodies such as ABET emphasize their inclusion in the curriculum, as shown by the fact that these objectives appear in several ABET student outcomes [5].

One of the challenges is that assessment of these learning objectives can be subjective [5]. An instructor could assess a student's demonstrated behavior with respect to a socio-technical learning objective to be positive, while another could deem it unacceptable. On the other hand, efforts to introduce standards could lead to prescriptive and restrictive assessment rules such as "a student must perform this action to meet this requirement", which can lead to other relevant behaviors being disregarded. Additionally, it can undermine the assessment activity since students may need to be prompted or steered towards performing a specific action in order to create the desired assessment scenario.

To address these challenges, we propose an assessment approach that applies semantic web technologies to produce non-subjective, quantitative assessment results. This solution includes an ontology model that represents activities within a classroom, and queries that unambiguously specify activity scenarios being assessed. We note at this time that this assessment approach is part of a larger project, which we refer to as the Smart Learning Environment (SLE) Ambient Assessment Framework (SLEAAF) and is depicted in Fig. 1. The SLEAAF consists of three major components: SLE activity recognition, the classroom activity ontology, and the assessment queries and outputs.

This particular work focuses on the latter two components, and provides an ontology model and queries that produce assessment results for several socio-technical learning objectives. In Fig. 1, the SLE simply produces the input data.

This material is based upon work supported by the National Science Foundation under Grant No. 2138846.

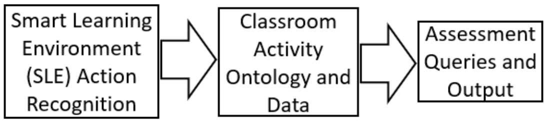

Figure 1: The Smart Learning Environment Ambient Assessment Framework

By cleanly separating the data generation from the data storage and processing components within the SLEAAF, we make our ontology and assessment framework agnostic to the data generation technology or method used.

The ontology model captures the classroom environment and the activities within so that semantic reasoning can be used to infer assessment conclusions. A major advantage of this ontology-based approach is that new queries can be created easily to fit an instructor's needs. Moreover, the ontology can be easily shared as a file that can be extended to incorporate new activities, which facilitates adoptability and adaptability. The proposed framework can be used as a tool for the education community to recommend assessment methods in a precise way in the form of database queries, which, prior to our work, could only be specified in a narrative way.

II. Background and Related Work

A. Assessment of Socio-Technical Learning Objectives in Engineering Courses

A significant body of work has been done on the subject of socio-technical skills assessment, however, only a few have applied technology to automate the process. In [6], e-portfolios are used to monitor student performance across a variety of assessment tools and see student improvement over a course of time. To mitigate the subjectivity that is inherent with this approach, the authors developed an assessment matrix based on Bloom's taxonomy learning progression (e.g. student's portfolio shows learning from "remembering" to "creating"). The work in [7] proposed that a take home exam is better than a sit-in, time constrained exam when it comes to assessing socio-technical skills so that students can work on open-ended questions related to socio-technical skills through their own research. However, the work did not provide specific questions that could readily be reused, thereby still requiring significant setup from any faculty who wishes to adopt this approach. The work in [8] applies the Defining Issues Test (DIT)-based approach in which students reflect on short scenarios that present ethical dilemmas. It was found that students retained lessons better if the scenarios used were actual ethical dilemmas that happened in previous teams of the same course. This of course, requires significant setup in the part of the instructor as they would need to develop scenarios based on (anonymized) actual teams. Some works attempt to provide structure in the assessment process by specifying a set of guidelines or components, such as the three-component framework from [9] and the six-step framework from [10]. From the assessment methods surveyed and evaluated in [11] and [12], a majority of the techniques are rubric-based, which could minimize subjectivity, but still suffers from it. Moreover, time-consuming faculty setup, administration and evaluation are a common thread among them.

B. Ontologies and Applications

Ontologies formally model concepts within a domain and relationships between them, respectively referred to as *classes* and *properties*. The ontology defines the schema of how classes are related through properties, whereas actual data, i.e. the instances of the defined classes, are captured as triples following the *subject-property-object* format. The World Wide Web Consortium (W3C) standardized the Resource Description Framework (RDF) data model for representing these triples. Within an RDF triple, the *subject* and *object* are instances of classes defined in the ontology and are related through the *property* [13].

Ontologies have been applied widely in the Semantic Web domain whereby resources on the internet (e.g. web pages, media, etc.) are classified into classes that are related together through properties. The benefit of storing data conforming to ontologies is that it allows for contextualized and flexible retrieval of the data. Ontologies have especially seen beneficial applications in eCommerce websites where products, users, preferences, and user activities are stored as RDF data, related to each other through well-defined properties. This allows eCommerce administrators to glean some context from the data [14]. Semantic approaches have also been applied to activity recognition in smart spaces [26][27], however, these works focused on the sensor and video devices that implement the smart space capabilities whereas our work focuses on the development of the ontology and queries specifically in the engineering education domain.

Currently, limited applications of ontologies can be found in the engineering education or smart classroom domain. The work in [15] developed an ontology to model an engineering curriculum, with [16] and [17] implementing a front-end system that allows semantic retrieval of curriculum information such as courses, topics and learning objectives. In [18], [19] and [20], the work is further extended to implement a user interface and an application programming interface.

The works in [21] and [22] are the smart classroom applications of ontologies that we have found to be most relevant to our work. Both are Internet of Things (IoT)-enabled approaches in which sensor data are stored in ontologies. In [22], ontologies are used to resolve classroom device interoperability, which is a domain-specific extension of knowledge-based approaches for resolving IoT device interoperability in general. In [21], semantic reasoning is used to automate certain events such as turning the lights on based on room occupancy. Neither of these works developed and used the ontologies towards assessment of student performance.

To the best of our knowledge, our work is the first to develop an ontology for modeling classroom activities for the purposes of supporting assessment of socio-technical behaviors and professional skills, and the first to use database queries to not only retrieve data, but to also specify the student activity scenarios that demonstrate specific attainment levels of socio-technical learning outcomes. Moreover, our ontology is designed with adoptability, adaptability and extensibility in mind.

III. Class Activity Ontology

A. Assessed Performance Indicators

The development of the class activity ontology is the knowledge engineering problem of producing an ontology that can represent the activities within a classroom. Since this objective is very broad, we narrow the scope by first identifying the specific scenarios we wish to assess, keeping in mind an incremental design so that new scenarios can be supported through straightforward additions to the ontology.

Three learning objectives inform the initial domain of our ontology: 1) demonstrates ethical behavior, 2) fosters constructive team climate, and 3) observes safety procedures. Since the learning objectives are fairly vague, there is a need to define observable student behaviors and interactions that describe specific scenarios that, if observed, assessment conclusions can be made. We refer to these scenarios as *performance indicators*. In this work, we develop knowledge-based assessment queries for the following six performance indicators:

1. Does not make up data.
2. Proactively turns off power supply at the end of lab activity for the safety of others.
3. Does not constantly interrupt others.
4. Contributes to group work.
5. Turns off power supply before making circuit changes.
6. Proactively wears antistatic wristband and uses the antistatic mat.

Performance indicators 1 and 2 are assessment scenarios for the "demonstrates ethical behavior" learning objective. Manufacturing data on lab reports goes against at least two fundamental canons of the National Society of Professional Engineers (NSPE) Code of Ethics for Engineers: "Issue public statements only in an objective and truthful manner" and "Avoid deceptive acts" [23], therefore, instilling honesty and integrity in engineering students is critical to their professional formation. The second performance indicator emphasizes the *proactivity* of the action because concern for the safety of others should be inherent in engineers. Performance indicators 3 and 4 are associated with the learning objective "fosters constructive team climate". Performance indicators 5 and 6, which are associated with the learning objective "observes safety procedures", again emphasize the proactivity of the actions.

B. Class Activity Ontology

To support data storage and knowledge-based assessment, we develop an ontology model that captures the activities within a specific classroom activity such as a "laboratory experiment". Specifically, the ontology is developed with an electric circuits laboratory activity in mind, which is assumed to involve students being placed into groups with assigned lab stations for the duration of the course activity. In section V, we discuss ways in which these assumptions and scenarios can be adapted or extended to support other types of course activities.

Fig. 2 shows the proposed classroom activity ontology. Central to the ontology is the class *Activity* which represents individual events performed by classroom occupants within a larger *CourseActivity*, such as "Lab 1" or "Group discussion 1". Activities are categorized as either *InstantActivity* or *IntervalActivity*, following conventions from ontologies

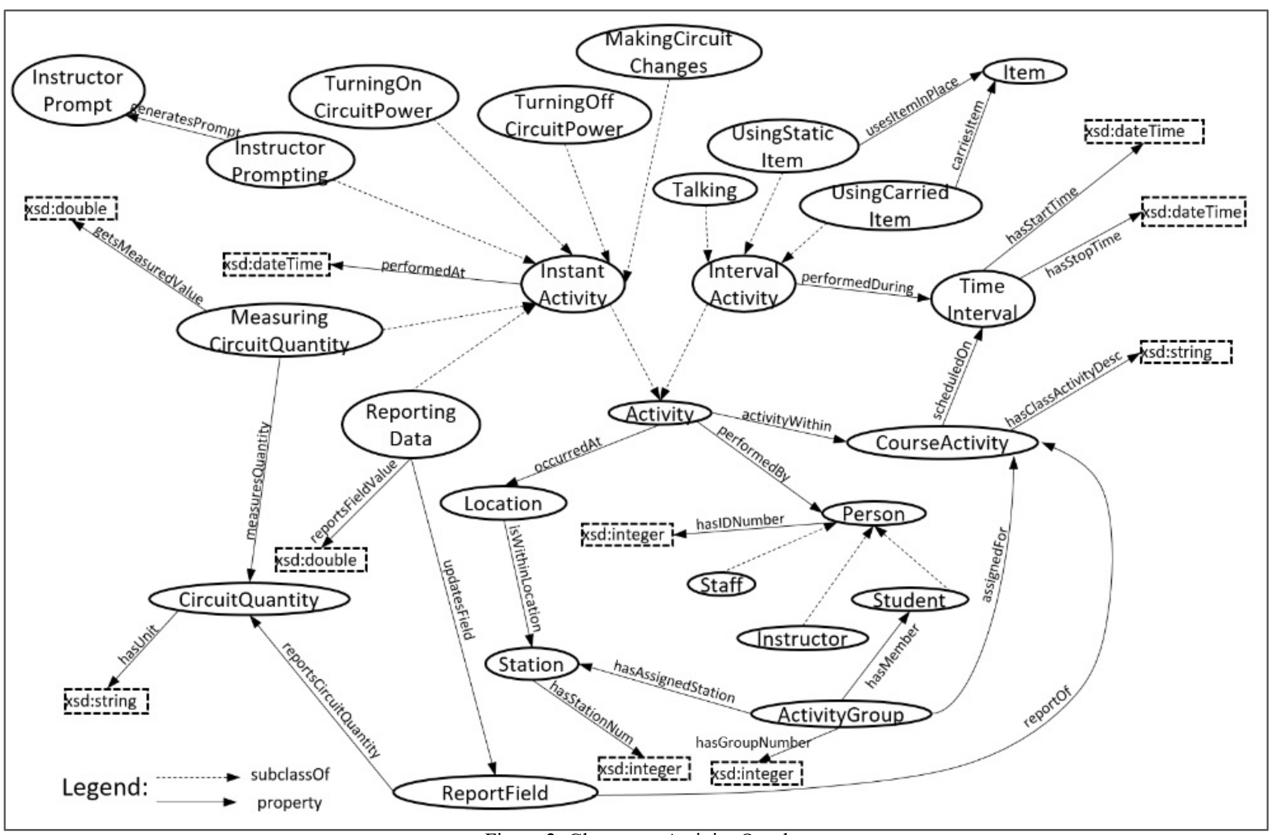

Figure 2: Classroom Activity Ontology

previously developed for the Activities of Daily Living (ADL) domain [25]. An *InstantActivity* activity is associated with a single timestamp of occurrence and while *IntervalActivity* activities are associated with a time duration with a "start time" timestamp and a "stop time" timestamp. Each activity is performed by a *Person*, who may be a *Student*, *Staff* or *Instructor*. Students are placed into groups for the duration of the course activity, identified as an *ActivityGroup* (e.g. Lab1Group1, Discussion1Group1…). Finally, each activity is associated with a location, which is an (X,Y) coordinate within the classroom facility; a location which may be designated to be within a *Station*, which represents zones within the facility such as a lab station or the podium.

Below, the *Activity* subclasses are discussed in detail, specifically in the context of an electric circuits laboratory course activity.

a) TurningOffCircuitPower and *TurningOnCircuitPower* – These activities simply capture the instant act of a person turning off or turning on the power supply to the circuit the student group is working on.

b) MakingCircuitChanges – This activity captures the action of a person making changes to the circuit, such as rewiring, unplugging components, or adding circuit elements.

c) MeasuringCircuitQuantity – This activity represents the event in which a person is measuring a circuit quantity such as current, voltage or resistance, using a measurement device such as multimeter. Each instance of this activity is associated with a measured value (via the *getsMeasuredValue* property) and a *CircuitQuantity* (via the *measuresQuantity* property). A *CircuitQuantity* individual is a specific quantity type and unit combination, such as current in milliamps, voltage in volts, or current in amps.

d) ReportingData – This activity captures the action of a person submitting a value for a specific *LabReportField* within a digital report. It is assumed that lab reports are digital forms with uniquely identifiable fields, each associated with a "submit" button or autosave feature so that the timestamp of value input is available. Each *LabReportField* is associated with a *CircuitQuantity*.

e) InstructorPrompting – This activity represents the event of the instructor providing announcements, reminders or directives to the class. These prompts may include:

- "Please wear the antistatic wristband."
- "Please use the antistatic mat."
- "Class activity time's up!"
- "Please turn off power supply before you leave."
- "Please put away the antistatic wristband before you leave."

f) Talking – This interval-type activity represents the event of a person talking for a duration of time. During a conversation between two people, the data will consist of a sequence of talking start and stop times for each person, each interval representing the duration in which a person is continuously speaking.

g) UsingStaticItem – This activity represents the duration in which a person is using an *Item* that is used in the same place throughout the duration of the activity. In the context of the circuit analysis lab activity being considered, an example is the antistatic mat, which is placed under the circuit the student group is working on.

h) UsingCarriedItem – This activity represents the event in which a person is using an item that is attached to their person. In our data, we consider the antistatic wristband as a carried item since it is worn around the person's wrist.

C. Data Generation and Assumptions

Since the focus of this work is the development of the classroom activity ontology and the assessment queries, and since the development of the SLE activity recognition component of the SLEAAF is currently in progress (see Fig. 1), we use mock data to develop and test our ontology and assessment queries. This approach provided several advantages: 1) the ontology and query development could take place in parallel with the SLE development phase; 2) the data generation and processing components of the SLEAAF are neatly separated, defining a clear interface between what type and format of data must be generated by the SLE, and what is expected by the data storage and processing components; 3) the process of mock data creation largely informed the SLE technology capability requirements and vice versa. In other words, the mock data were not arbitrarily created, but are based on emergent SLE activity recognition capabilities being developed – the development of which was also informed by the creation of mock data. Hence, the concurrent development of the ontology, mock data and SLE technologies was necessary.

Upon completion, the SLE technologies being developed as part of the SLEAAF project (see section I, Fig. 1) will be able to automatically generate the data ambiently using sensors, data logging instruments such as a datalogging multimeter, microphones, cameras and sophisticated natural language and activity recognition processing software, much of which are readily available from python libraries and cloud services. However, in the absence of such SLE technologies, data can also be obtained through manual [21] or machine learning-based [24] post processing of recorded videos. Alternatively, participants may be asked to self-annotate their activities [25].

An additional assumption that needs to be clarified with respect to the ontology and data, is that the domain of the ontology as shown in Fig. 2 is a single course section, e.g. Spring 2022 Circuit Analysis 1, Section 001. This means that all individuals of the classes must be associated with a unique identifier within this domain. For example, each *Activity* individual has an identifier that is unique throughout the course; the same can be said about classes such as *ActivityGroup* (e.g. *Lab1Group1*, *Lab2Group2*, …) and *LabReportField* (e.g. *Lab1RF1*, *Lab1RF2*…). It should be noted that extending the ontology to account for multiple courses or sections of courses is straightforward, and can be done by creating named graphs or adding a new class, *Course*, that each *CourseActivity* is associated with.

IV. Knowledge-Based Assessment Implementation and Results

A. Ontology Development

The Class Activity ontology was developed and validated using Protégé ontology editor [28]. Fig. 3 shows the class hierarchy. As prescribed by the Web Ontology Language (OWL), two types of properties are defined – object properties whose range include other classes, and data properties, whose range include literal data values such as an integer, string or date. The ontology is verified using Protégé's built-in HermitT reasoner, and is saved as a .OWL file for sharing and reuse[1].

Figure 3: Protege Class hierarchy and properties

B. Data Storage and Query Framework

Apache Jena, a Java framework that is widely used in semantic web applications [29], is used in the implementation and data storage. The RDF triples are serialized using Turtle syntax [30], stored in TDB, Jena's persistent storage component for RDF storage and query, and exposed for querying using Fuseki, Jena's SPARQL server. The assessment queries are written in the SPARQL Protocol and RDF Query Language (recursively SPARQL) [31].

C. SPARQL Assessment Queries

In this section, we provide SPARQL queries that formalize assessment questions for the six performance indicators discussed in section III.A. These queries serve as a proof-of-concept for how assessments can be formally pre-developed, shared, recommended or prescribed among engineering educators, but at the same time, allow full flexibility since these queries can be adopted, adapted, or simply used as examples for developing new queries.

a) Performance Indicator: Does not make up data.

The first assessment query to be examined is related to the performance indicator *"*does not make up data" associated with the course or program learning objective *"*demonstrates ethical behavior*"*. Our aim is to design a query that would answer the question "*What percent of a student's data reports is preceded by a corresponding measurement for that data?*"

To answer this question, we determine the fraction of *ReportingData* activities of a student that is preceded by a matching and qualifying *MeasuringCircuitQuantity* activity. We define that the *MeasuringCircuitQuantity* activity is a match if the circuit quantity measured is the same as that of the reported value (e.g. current), and it is performed by any member of the group. To determine whether a *MeasuringCircuitQuantity* is qualified, two input arguments are used – a maximum time window and a maximum percentage difference. The maximum time window specifies the time window before the data is reported over which we look for a possible corresponding *MeasuringCircuitQuantity* activity. For example, if a *MeasuringCircuitQuantity* activity appears in our data an hour before a ReportingData activity, the two are likely not related. The maximum percent difference filters out *MeasuringCircuitQuantity* activities that logged values that are completely different from the reported values.

Table 1 shows a SPARQL query that returns the percent value previously described, which is our numerical assessment result. The query specifies four input arguments that are tunable (lines 25-26) – the student ID of the student being assessed (`stid`), the *CourseActivity* individual (`lab`), the maximum time window (`maxtwin`) and the maximum percentage

Table 1: SPARQL assessment query for "does not make up data"

```
1.  SELECT (((COUNT(DISTINCT ?minpdiff))
2.    /(COUNT(DISTINCT ?actrep2)))*100 as ?res)
3.  WHERE{ ?actrep2 a :ReportingData ;
4.      :activityWithin ?lab ;
5.      :performedBy ?stid .
6.    {SELECT (min(?percentdiff) AS ?minpdiff)
7.      (sample(?stid) as ?stid)
8.      (sample(?lab) as ?lab)
9.    WHERE{ SELECT * WHERE{
10.       ?group :hasMember ?stid .
11.       ?group :hasMember ?grpmems .
12.       ?actmeasure :performedBy ?grpmems ;
13.         a :MeasuringCircuitQuantity ;
14.         :performedAt ?mtime ;
15.         :activityWithin ?lab ;
16.         :getsMeasuredValue ?measuredvals ;
17.         :measuresQuantity ?meascirqty .
18.       BIND(?rtime - ?mtime AS ?tdiff) .
19.       BIND((abs(?measuredvals-?reportvals)
20.          /((?measuredvals+?reportvals)/2))
21.             *100 AS ?percentdiff) .
22.       FILTER(?tdiff >= 0  && ?tdiff <= ?maxtwin
23.          && ?percentdiff<?maxpdiff
24.          && ?meascirqty = ?rcqty) .
25.       {SELECT * WHERE { VALUES (?stid ?lab
26.        ?maxtwin ?maxpdiff){(:ID07 :Lab1 100 5)}
27.         ?actrep a :ReportingData ;
28.           :activityWithin ?lab ;
29.           :performedBy ?stid ;
30.           :performedAt ?rtime ;
31.           :updatesField ?rfld ;
32.           :reportsFieldValue ?reportvals .
33.         ?rfld :reportsCircuitQuantity ?rcqty ;
34.           :reportOf ?lab .}}}
35.   } GROUP BY ?actrep }}
```

[1]The ClassActivity.owl, mockdata ttl and query .rq files are available at https://github.com/SLEResearch/ClassActivityOntology/

difference (maxpdiff). Lines 27-34 identify the *ReportingData* activities performed by the student being assessed, as well as the value and circuit quantity type being reported.

Lines 10-17 retrieve the *MeasuringCircuitQuantity* activities performed by all members of the group, and lines 18-24 filter for those that match and qualify with respect to the time window and percentage difference. Because there could be several preceding *MeasuringCircuitQuantity* activity logs of the same event (e.g. the instrument fluctuates resulting in several measured log entries), we look for the measured value closest to the reported value (line 6).

b) Performance Indicator: Proactively turns off power supply at the end of lab activity for the safety of others.

To assess this performance indicator, which is relevant to the learning objective "demonstrates ethical behavior", we seek to determine whether the group turned off the power supply at the end of the lab activity prior to the instructor prompting the class to do so. Like with safety-related behaviors, *proactive* action is most critical in this scenario, indicating that without prompting, the student is inherently concerned about the safety of others. Of course, this performance indicator can also be used towards assessing the learning objective "observes safety procedures", which further illustrates the flexibility of our approach.

The SPARQL query in Table 2 returns a binary value 0 or 1, with the latter indicating that the student met the objective. Since it is assumed that there is only one power supply within the station, the result is a group behavior assessment, although student-specific assessment is possible by observing behaviors over several course activities (e.g. "*is student x always the one that turns off the power supply regardless of what group they are placed in?*"). Lines 11-22 retrieve the set actall, which includes the *MakingCircuitChanges*, *TurningOffCircuitPower* and *TurningOnCircuitPower* activities performed by all group members (all other activity types are irrelevant in this scenario).

TABLE 2: SPARQL ASSESSMENT QUERY FOR "PROACTIVELY TURNS OFF POWER SUPPLY AT THE END OF THE COURSE ACTIVITY"

```
1.  SELECT (COUNT(DISTINCT ?actall) AS ?turnedoff)
2.  WHERE{ ?instructor a :Instructor .
3.    ?promptend :performedBy ?instructor ;
4.      a :InstructorPrompting ;
5.      :generatesPrompt :TurnOffCircuit ;
6.      :performedAt ?prompttime .
7.    ?actall a ?acttype2 .
8.    ?actall :performedAt ?lastact .
9.    FILTER (?acttype2 = :TurningOffCircuitPower
10.     && ?lastact < ?prompttime){
11.     SELECT DISTINCT ?actall ?acttime
12.     WHERE{ VALUES (?stid ?lab) {(:ID09 :Lab1)}
13.       ?group :hasMember ?stid .
14.       ?group :hasMember ?grpmem .
15.       ?actall :performedBy ?grpmem ;
16.         a ?acttype ;
17.         :performedAt ?acttime ;
18.         :activityWithin ?lab .
19.       FILTER(?acttype IN (
20.         :MakingCircuitChanges,
21.         :TurningOffCircuitPower,
22.         :TurningOnCircuitPower)) .
23.     }ORDER BY DESC(?acttime) LIMIT 1 }}
```

Among these activities, the last one performed is identified via the ORDER… LIMIT 1 aggregation of line 23. Lines 2-6 identify the *InstructorPrompting* activity in which the instructor prompts the class to turn off the power supply just before ending the course activity. The FILTER statement in lines 9-10 determines whether the last activity within actall is of type TurningOffCircuitPower.

c) Performance Indicator: Does not constantly interrupt others.

To assess the performance indicator "Does not constantly interrupt others" associated with the socio-technical learning objective "Fosters constructive team climate", we seek to answer the question "What percent of their groupmates' talking intervals does the student interrupt?". The relevant activity class here is "Talking", which has an associated time interval *startTime* and *stopTime*. During the course activity, there may be many *Talking* intervals between two or more students within the group. The SPARQL query in Table 3 returns:

$$\frac{\text{\# of Talking intervals done by \{group\}\textbackslash\{stid\} interrupted by stid}}{\text{\# of Talking activities done by \{group\}\textbackslash\{stid\}}} x100$$

The only inputs to the query are the ID of the student and the course activity of interest provided in line 21. The SELECT query in lines 19-28 retrieve all the relevant *Talking* intervals of the student (acttalk1). Lines 4-12 retrieve all the *Talking* intervals of other members of the group, excluding the student being assessed (acttalk2). The outer SELECT statement allows us to compare every pair of acttalk1 and acttalk2 instances and look for pairs in which acttalk1's start time is in between an acttalk2's start and stop times (lines 16-17). This query outputs a value between 0 and 100, indicating the percent of their groupmate(s)' *Talking* intervals that are interrupted by the student.

TABLE 3: SPARQL ASSESSMENT QUERY FOR "DOES NOT INTERRUPT OTHERS"

```
1.  SELECT (((COUNT(DISTINCT ?acttalk2)
2.      /COUNT(DISTINCT ?acttalk3))*100) AS ?res)
3.  WHERE {
4.      ?group :hasMember ?stid .
5.      ?group :hasMember ?grpmem .
6.      FILTER (?grpmem != ?stid) .
7.      ?acttalk2 a :Talking ;
8.              :activityWithin ?lab ;
9.              :performedBy ?grpmem ;
10.             :performedDuring ?TI2 .
11.     ?TI2 :hasStartTime ?TI2_start ;
12.             :hasStopTime ?TI2_stop .
13.     ?acttalk3 a :Talking ;
14.             :activityWithin ?lab ;
15.             :performedBy ?grpmem ;
16.     FILTER(?TI1_start > ?TI2_start
17.             && ?TI1_start < ?TI2_stop) .
18.     {
19.     SELECT ?stid ?lab ?acttalk1
20.             ?TI1_start ?TI1_stop
21.     WHERE {VALUES (?stid ?lab) {(:ID07 :Lab1)}
22.             ?acttalk1 a :Talking ;
23.                     :activityWithin ?lab ;
24.                     :performedBy ?stid ;
25.                     :performedDuring ?TI1
26.             ?TI1 :hasStartTime ?TI1_start ;
27.                     :hasStopTime ?TI1_stop .}}}
```

TABLE 4: SPARQL ASSESSMENT QUERY FOR "CONTRIBUTES TO GROUP WORK"

```
1. SELECT  (((COUNT(DISTINCT ?act)
2.     /COUNT(DISTINCT ?groupact))
3.     *100) AS ?contribution)
4. WHERE { VALUES ?stid {:ID08}
5.    ?group :hasMember ?stid .
6.    ?group :hasMember ?grpmem .
7.    ?groupact :performedBy ?grpmem .
8.    ?act :performedBy ?stid .
9.    ?act a ?acttype .
10.   FILTER (?acttype IN (
11.      :MeasuringCircuitQuantity,
12.      :Talking, :ReportingData,
13.      :MakingCircuitChanges,
14.      :TurningOffCircuitPower,
15.      :TurningOnCircuitPower)) .}
```

d) Performance Indicator: Contributes to group work.

To assess this performance indicator, we first identify several activity types that can be considered as contribution to the group work. In the current ontology, these are identified to be *MeasuringCircuitQuantity*, *Talking*, *ReportingData*, *MakingCircuitChanges*, *TurningOffCircuitPower* and *TurningOnCircuitPower*, noting that any new class can be easily added to the list.

The SPARQL query shown in Table 4 specifies the ID of the student of interest (`stid`) in line 4. Lines 6-7 retrieve the relevant activities performed by all members of the group, whereas lines 8-9 retrieve those performed by just `stid`. Lines 11-15 specify the types of activities considered to be a contribution to the group work. The contribution is derived from the ratio between their respective counts (lines 1-3).

e) Performance Indicator: Turns off power supply before making circuit changes.

The SPARQL query in Table 5 returns the percent of time in which *MakingCircuitChanges* activities by the student of interest (`stid`) is preceded by a *TurningOffCircuitPower* activity by anyone from the group, and not by a *TurningOnCircuitPower* or another *MakingCircuitChanges* activity, henceforth referred to in this section as the *circuit changer* activities for ease of discussion. First, all circuit changer activities of the group are retrieved in lines 22-33 as `actall`. Lines 17-21 retrieve just the *MakingCircuitChanges* activities of `stid` (`actmcc`). For each `actmcc`, the `actall` activity with the smallest positive time difference is determined (lines 13 and 36), and this time difference is saved as `tlast` in line 14. Assuming that the circuit changer activities do not occur at the same time within a group, the type of the circuit changer activity is identified by matching the time stamps `tlast`. If this is determined to be of type *TurningOffCircuitPower*, we conclude the circuit power was turned off before changes were made to the circuit. The percentage of such matches is outputted as the result.

f) Performance Indicator: Proactively wears antistatic wristband and uses the antistatic mat.

The SPARQL query in Table 6 returns a categorical value based on if and when a student uses the antistatic wristband and

TABLE 5: SPARQL ASSESSMENT QUERY FOR "TURNS OFF POWER SUPPLY BEFORE MAKING CIRCUIT CHANGES"

```
1. SELECT ((COUNT(DISTINCT ?acttocp)
2.   /COUNT(DISTINCT ?actmcc))*100 AS ?output)
3. WHERE{ ?group :hasMember ?stid .
4.   ?group :hasMember ?grpmems .
5.   ?actmcc :performedBy ?grpmems ;
6.     :activityWithin ?lab ;
7.     a :MakingCircuitChanges .
8.   ?acttocp a :TurningOffCircuitPower ;
9.     :activityWithin ?lab ;
10.    :performedBy ?grpmems ;
11.    :performedAt ?acttocptime .
12.  FILTER (?acttocptime = ?tlast)
13.  { SELECT ?tmcc (min(?tdiff) as ?tdifflast)
14.    (?tmcc-?tdifflast AS ?tlast)
15.  (sample(?stid) AS ?stid)(sample(?lab) AS ?lab)
16.    WHERE{?group :hasMember ?stid .
17.      ?group :hasMember ?grpmems .
18.      ?actmcc :performedBy ?grpmems ;
19.        a :MakingCircuitChanges ;
20.        :activityWithin ?lab ;
21.        :performedAt ?tmcc
22.      {SELECT * WHERE{
23.        VALUES (?stid ?lab) {(:ID10 :Lab1)}
24.        ?group :hasMember ?stid .
25.        ?group :hasMember ?grpmems .
26.        ?actall :performedBy ?grpmems ;
27.         a ?acttype ;
28.         :activityWithin ?lab ;
29.         :performedAt ?tall .
30.        FILTER (?acttype IN (
31.             :MakingCircuitChanges,
32.             :TurningOffCircuitPower,
33.             :TurningOnCircuitPower)) . }}
34.        BIND((?tmcc-?tall) AS ?tdiff) .
35.           FILTER(?tdiff > 0)}
36.       GROUP BY ?tmcc }}
```

mat. Although a student may use and put away both of these multiple times during the course activity, we only examine the first such event because we emphasize the proactivity of the action when it comes to safety precautions. In addition to the student ID and course activity inputs, the query takes an additional third input, the ID of the instructor, `prid` (lines 2-3). Lines 4-7 and 14-15 respectively retrieve the times of the instructor's "put on your antistatic wristband" and "use the antistatic mat" prompts.

Lines 8-13 determines the time the student puts on the antistatic wristband (since this is an *IntervalActivity* type of activity, the start time of the interval is used in line 13), while lines 18-23 determine the same for the antistatic mat. The `COALESCE` function in line 26 outputs a categorical assessment result based on the following criteria:

- "Exceeds expectations" if the student uses both the wristband and mat before the instructor prompts for either.
- "Meets expectations" if the student uses both items but at least one of them is used only after the instructor's reminder.
- "Needs improvement" if both the mat and wristband are used only after the instructor's reminders.

- “Unacceptable” for all other cases, including if a student never uses either item during the course activity.

V. EXTENDING THE FRAMEWORK

One of the major objectives of our work is to provide a framework that can be reused, customized or extended. It is clear from the six assessment queries provided that more can be created if the activity scenario is defined in terms of the ontology classes and properties. To illustrate the flexibility of the framework, consider if “tidying up” is determined to be illustrative of a professional behavior, and we wish to determine if a student is proactively putting away the antistatic mat at the end of the lab activity. A significant portion of the query from Table 2 can be reused for this scenario. In this case, a possible query would look to see if the “stop time” of the student’s *UsingStaticItem* activity for the mat occurs within a reasonable time window of the course activity’s stop time. The parameters of the time window would be tuned so that it is not before the last circuit changer activity (see section IV.C.e).

It is also possible that the desired activity scenario is currently not supported by the ontology as defined in section III. In these cases, the ontology can be extended to add new classes and properties to accommodate new activities, as long as the activity can be sufficiently represented by an RDF triple. Below are some examples of possible ontology additions to support new assessment scenarios:

TABLE 6: SPARQL ASSESSMENT QUERY FOR "PROACTIVELY USES ANTISTATIC WRISTBAND AND MAT"

```
SELECT ?result
WHERE { VALUES (?stid ?lab ?prid)
  {(:ID03 :Lab1 :ID13)}
  ?prompt1 :generatesPrompt :PutOnWristBand ;
     :performedAt ?prompt1t ;
     :performedBy ?prid ;
     :activityWithin ?lab .
  ?studentWearsBand a :UsingCarriedItem ;
     :activityWithin ?lab ;
     :carriesItem :AntistaticBand ;
     :performedBy ?stid ;
     :performedDuring ?timeInt1 .
  ?timeInt1 :hasStartTime ?t1start .
  ?prompt2 :generatesPrompt :UseMat ;
     :performedAt ?prompt2t ;
     :performedBy ?prid ;
     :activityWithin ?lab .
  ?studentUsesMat a :UsingStaticItem ;
     :activityWithin ?lab ;
     :usesItemInPlace :AntistaticMat ;
     :performedBy ?stid ;
     :performedDuring ?timeInt2 .
  ?timeInt2 :hasStartTime ?t2start .
  ?lab :scheduledOn ?labti .
  ?labti :hasStopTime ?labend .
  BIND( COALESCE(
    IF(?prompt1t > ?t1start && ?prompt2t >
       ?t2start, "exceeds expectations", 1/0),
    IF((?prompt1t > ?t1start && ?prompt2t
       <= ?t2start && ?t2start < ?labend)||
      (?prompt1t <= ?t1start && ?prompt2t >
      ?t2start && ?t1start < ?labend),
      "meets expectations",1/0),
    IF(?t1start < ?labend && ?t2start
       < ?labend, "needs improvement",1/0),
      "unacceptable") AS ?result)}
```

- Determine whether a student is participating in a class discussion by responding to instructor questions. To support this, a new *InstructorPrompt* individual representing “Ask a question” may be added, which actually doesn’t require changes to the ontology. The existing ontology already has support for the *Talking* activity, whose interval can be checked if the start time is soon after the prompt. These activities are then associated with a different *CourseActivity* individual, such as “Class Discussion” instead of a Laboratory Experiment.
- Determine whether a student is exhibiting leadership skills by asking other students some questions. The ontology can be extended to add an *InstantActivity* e.g. *AskingQuestion*, and to add a new type of *CourseActivity*, e.g. “Group Discussion”.
- Other safety-related activities can be added such as “Wearing goggles”. In this case, the existing relationship between *UsingCarriedItem* and *Item* can be used, with “goggles” as a new individual of *Item*.

VI. CONCLUSION AND FUTURE WORK

Assessment of socio-technical learning objectives in engineering education is a grand challenge. While technical knowledge and skills can be easily assessed by instructors through traditional assessment methods such as exams and project demonstrations, existing assessment methods for socio-technical learning objectives come with several challenges, including being 1) challenging to design, 2) time-consuming to administer, 3) inconsistent in its subjectivity, and 4) slow in returning feedback to students. Our work introduces a novel knowledge-based assessment framework which includes a class activity ontology as well as assessment queries that can address all of these challenges. Our approach may remove the need to design and create elaborate settings where students’ socio-technical behaviors can be observed in; rather, students are left to go about course activities such as lab experiments and group discussions as normal. Moreover, we provide several queries that unambiguously specify the behaviors and scenarios being assessed, which output quantitative results, thereby addressing the subjectivity of existing methods. Finally, query results can be obtained quickly, even in real time (as long as the class activity RDF data is available), therefore, feedback to students can be returned with very little delay.

The ontology and query framework introduced in this work is part of an ongoing project, the SLEAAF introduced in section I. For our future work, SLE capabilities will be integrated to the system so that the RDF data are generated in real time using ambient Internet of Things technologies.

References

[1] A. Cheville, "Defining Engineering Education," Paper presented at 2014 ASEE Annual Conference & Exposition, Indianapolis, Indiana, June 2014, 10.18260/1-2--20248

[2] "The Engineer of 2020: Visions of Engineering in the New Century," Washington, DC: The National Academies Press. https://doi.org/10.17226/10999.

[3] K. Anderson, S. Courter, T. McGlamery, T. Nathans-Kelly, C. Nicometo, "Understanding The Current Work And Values Of Professional Engineers: Implications For Engineering Education," Paper presented at 2009 Annual Conference & Exposition, Austin, Texas, June 2009, 10.18260/1-2—4625

[4] W. H. Abulfaraj, M. H. Hassan, "Teaching and assessment of professional ethics in the nuclear engineering education according to the ABET Engineering Criteria," 2007 American Society of Engineering Education Annual Conference & Exposition June 24-27, 2007 -Honolulu, USA.

[5] L. J. Shuman, M. Besterfield-Sacre, J. McGourty, The ABET "Professional Skills" – Can They Be Taught? Can They Be Assessed?" Journal of Engineering Education - 1- Vol. 94, No. 1, 2005

[6] L. McNair, M. Paretti, M. Knott and M. L. Wolfe, "Work in Progress: Using e-Portfolio to Define, Teach, and Assess ABET Professional Skills," Proceedings. Frontiers in Education. 36th Annual Conference, 2006, pp. 13-14, doi: 10.1109/FIE.2006.322551.

[7] D. López, J. -L. Cruz, F. Sánchez and A. Fernández, "A take-home exam to assess professional skills," 2011 Frontiers in Education Conference (FIE), 2011, pp. F1C-1-F1C-6, doi: 10.1109/FIE.2011.6142797.

[8] C. P. Titus, C. B. Zoltowski and W. C. Oakes, "Work in progress — Assessing moral decision making skills in the engineers of 2020," 2010 IEEE Frontiers in Education Conference (FIE), 2010, pp. S3E-1-S3E-2, doi: 10.1109/FIE.2010.5673149.

[9] K. Schoepp, M. Danaher and A. A. Kranov, "The computing professional skills assessment: An innovative method for assessing ABET's student outcomes," 2016 IEEE Global Engineering Education Conference (EDUCON), 2016, pp. 45-52, doi: 10.1109/EDUCON.2016.7474529.

[10] C. L. Garay-Rondero, E. Z. R. Calvo and D. E. Salinas-Navarro, "Developing and Assessing Engineering Competencies at Experiential Learning Spaces," 2019 IEEE Frontiers in Education Conference (FIE), 2019, pp. 1-5, doi: 10.1109/FIE43999.2019.9028355.

[11] D. W. Knight, A. R. Bielefeldt, C. Swan, N. E. Canney and M. Polmear, "Exploring the Range of Methods Used to Assess Engineering Students' Education on Ethical and Societal Impact Issues," 2018 IEEE Frontiers in Education Conference (FIE), 2018, pp. 1-7, doi: 10.1109/FIE.2018.8658582.

[12] J.L. Hess & G. Fore. "A Systematic Literature Review of US Engineering Ethics Interventions." Sci Eng Ethics (2018) 24: 551. https://doi.org/10.1007/s11948-017-9910-6ref

[13] N. F. Noy, D. L. Mcguinness, "Ontology Development 101: A Guide to Creating Your First Ontology", Stanford Knowledge Systems Laboratory Technical Report KSL-01-05 and Stanford Medical Informatics Technical Report, SMI-2001-0880, March 2001.

[14] S. C. Necula, V. Pavaloaia, C. Strimbei, O. Dospinescu, "Enhancement of E-Commerce Websites with Semantic Web Technologies" (2018). Sustainability. 10. 1955. 10.3390/su10061955.

[15] T.C. Ling, Y. Y. Jusoh, R. Adbullah, N. H. Alwi, "An Ontology for Software Engineering Education," International Conference on Educational Technologies 2013, ISBN: 978-972-8939-99-1

[16] L. N. Cassel, et. al, "The Computing Ontology: Application in Education," ACM SIGCSE Bulletin Vol. 39, No. 4, pp. 171-183, 2007.

[17] Cassel, L., G. Davies, R. LeBlanc, L. Snyder, H. Topi, "Using a computing ontology as a foundation for curriculum development," Sixth International Workshop on Ontologies and Semantic Web for E-learning, 2008

[18] A. Tang, A. Abdur Rahman, "Proof-of-Concept design of an ontologybased computing curricula management system," Proc. Digital Information and Communication Technology and Its applications (DICTAP2011), CCIS (LNCS) vol. 167, H. Cherifi, J.M. Zain, E. ElQawasmeh, Eds. Heidelberg: Springer, 2011, pp. 280–292.

[19] A. Tang, "Towards the use of a Computing Ontology: A curricula management system proposal," International J. of Digital Information and Wireless Comm., vol. 1, Nov. 2011, pp. 94-108, http://sdiwc.net/digital-library/web-admin/upload-pdf/00000100.pdf

[20] A. Tang and J. Hoh, "Ontology-specific API for a Curricula Management System," 2013 Second International Conference on E-Learning and E-Technologies in Education (ICEEE), 2013, pp. 294-297, doi: 10.1109/ICeLeTE.2013.6644391.

[21] K. Maria, E. Vasilis and A. Grigoris, "S-CRETA: smart classroom real-time assistance", In Ambient Intelligence-Software and Applications , pp. 67-74, Springer, Berlin, Heidelberg, 2012

[22] S. D. Nagowah, H. ben Sta and B. A. Gobin-Rahimbux, "An Ontology for an IoT-enabled Smart Classroom in a University Campus," 2019 International Conference on Computational Intelligence and Knowledge Economy (ICCIKE), 2019, pp. 626-631, doi: 10.1109/ICCIKE47802.2019.9004369.

[23] The National Society of Professional Engineers. NSPE Code of Ethics for engineers. JOM 45, 14–16 (1993). https://doi.org/10.1007/BF03223280

[24] X. Li, M. Wang, W. Zeng and W. Lu, "A Students' Action Recognition Database In Smart Classroom," 2019 14th International Conference on Computer Science & Education (ICCSE), 2019, pp. 523-527, doi: 10.1109/ICCSE.2019.8845330.

[25] P. R. Woznowski, E. L. Tonkin, P. A Flach, "Activities of Daily Living Ontology for Ubiquitous Systems: Development and Evaluation", Sensors (Basel), vol. 18(7), 2018, doi:10.3390/s18072361

[26]] L. Chen, C. D. Nugent and H. Wang, "A Knowledge-Driven Approach to Activity Recognition in Smart Homes," in IEEE Transactions on Knowledge and Data Engineering, vol. 24, no. 6, pp. 961-974, June 2012, doi: 10.1109/TKDE.2011.51.

[27] D. Mitchell, P. J. Morrow and C. D. Nugent, "A sensor and video based ontology for activity recognition in smart environments," 2014 36th Annual International Conference of the IEEE Engineering in Medicine and Biology Society, 2014, pp. 5932-5935, doi: 10.1109/EMBC.2014.6944979.

[28] *Protégé Ontology Editor*. (5.5.0). Stanford Center for Biomedical Informatics Research. Accessed: Jan. 27, 2022. [Online]. Available: https://protege.stanford.edu/

[29] *Apache Jena*. (4.5.0). The Apache Software Foundation. Accessed: April 24, 2022. [Online]. Available: https://jena.apache.org/

[30] *RDF 1.1 Turtle*. (Feb. 2014). World Wide Web Consortium. Accessed: June 20, 2022. [Online]. Available: https://www.w3.org/TR/turtle/

[31] *SPARQL Query Language for RDF*. (Jan. 2008). World Wide Web Consortium. Accessed: June 20, 2022. [Online]. Available: https://www.w3.org/TR/rdf-sparql-query/

.

.