**CLARK – The Cybersecurity Labs and Resource Knowledge-base – A Living Digital Library**

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It is clear that in order to address the cybersecurity education and workforce crisis, the challenges are not just numerous but also inextricably linked. The least of which include a greater number of prepared faculty, effective curriculum, and infrastructure to host, use, and disseminate the curriculum. There is a demonstrated need for a cybersecurity digital library (DL) that will help address these challenges. The Cyber DL is similar to other curricular digital libraries in some respects (material quality, uptake, etc.) and unique in others (national security concerns, presence of damaging material – malware, material integrity issues, etc.).

We have been working on the design and implementation of CLARK – The Cybersecurity Labs and Resource Knowledge-base. CLARK is a prototype curriculum management platform that hosts diverse cybersecurity learning objects. This submission introduces the system and highlights its capabilities as a tool that is much needed in the cybersecurity education community. The system has three distinct components, each based in research in the learning sciences and the need for a usable and sustainable cybersecurity curricular library. These are:

1. A learning-outcomes based submission – Curriculum entered into the digital library needs to outline learning goals and outcomes (based on the blooms taxonomy), corresponding assessment techniques, and appropriate instructional strategies. This provides a curation process to allow effective learning materials to be housed in the knowledge-base while reducing the barrier for entry.
2. A scalable template-based storage – Curriculum in the system adheres to templates for course, units, modules, micro-modules, and nano-modules [1]. The templates are flexible and the system allows for other templates and formats that contributors use to be added.
3. A faceted search - There are many users of the cybersecurity curriculum. They are in all sectors (government, industry, academia), different levels (job training, K-12 and above), and have diverse use-cases (curriculum to satisfy CAE designations and accreditation, creation of courses or entire programs, or learning materials at a certain level in the blooms taxonomy). The CLARK search provides flexible and usable interfaces for these users.

**Learning-outcomes based submission**

The CLARK system is based on a learning-outcomes based submission of curricular content. Each submission will need to clearly need to:

- outline learning goals and outcomes (based on the Bloom's taxonomy)
- corresponding assessment techniques (questions, projects, etc.), and
- appropriate instructional strategies (lectures, case studies, etc.)

This provides a curation process to allow effective learning materials to be housed in the knowledge-base while keeping a barrier of entry that ensures only measurably effective curriculum is submitted. Encouraging content creators to explicitly defined learning outcomes and associated data will greatly increase the usability of the materials by academics along with easing the path to assessing the materials.

As part of the submission process, the CLARK system prototypes a "LO Suggestion" functionality. The system suggests meta-data with semantic annotations based on the Bloom's Taxonomy, CAE Knowledge Units (KU), and the NICE Cybersecurity Workforce Framework (NCWF). For instance, when content creators enter learning outcomes (LO) for materials, the proposed system suggests LOs from CAE KUs and NCWF to map the materials to. This "LO suggestion" functionality is similar to the keyword suggestion provided by a search engine. The functionality facilitates mapping and allow enhance searching.

**Template-based storage**

There is a diversity of effective cybersecurity curriculum that has been created in academia, industry, and government. These learning materials have been created using various formats and for different purposes in the classroom (classes, labs, case-studies, etc.). A curriculum management system needs to flexible to accept various formats, while enforcing certain guidelines on the materials submitted. These guidelines (hereafter, referred to as 'templates') will ensure that curriculum materials meets standards of quality of presentation, contains

good pedagogy strategies, is usable and accessible, adheres for copyright restrictions, and is complete and ready to use for teaching.

**Faceted search**

Quality curriculum needs to be quick to find and easy to use for time-strapped faculty. Depending on the use-case, a system should be able to provide the most efficient access for a user. For instance, some faculty exclusively teach CS1 and CS2 classes. If such a faculty is searching for cybersecurity curriculum to be used in a "CS1" class, then the fastest way may be a browsing interface based on classes. Another use-case may be a faculty hoping to find curriculum to satisfy a certain CAE KU requirement – this may be another browsing scenario. However, some scenarios lend themselves better to searching, for instance a faculty looking for modules on "confidentiality" or "software assurance" – topic that naturally span many classes. CLARK provides searching and browsing with multiple interfaces servicing specific needs.

In addition to providing an easy interface to build LOs using the Bloom's Taxonomy, the LO-based submission allows searching not just based on topics, but also level of learning based on the taxonomy (Query 1).

**Table 1. Potential queries in the CLARK system**

| |
|---|
| Query 1 - "Find me *nano-modules* that allow students to **understand** the attack vectors associated with industrial control systems" |
| Query 2 - "Find me *modules* that allow students to **evaluate** the risk associated attack vectors associated with industrial control systems" |

*Note:* The *italics* is the learning object class, **bold** is the Bloom's taxonomy level, and underlined is the CAE KU (or NCWF KSAs)

For Query 2, the goal is that the retrieval component would be able to use semantic annotations to return materials based on compositions of the class of learning objects, for instance a 'module' that will allow students to 'evaluate' the risk would require nano-modules to 'understand' followed by other higher-level modules. Even though the ultimate decisions on such compositions will be made by the human, this will greatly enhance the search process. We plan to enhance the system such that these functionalities are a possibility.

**Demo and Video**

CLARK is currently hosted at www.clark.center and has 116 learning objects entered by 38 curriculum developers.

Demonstration video 1: https://youtu.be/gPVw4z264GA Building and uploading a learning object

Demonstration video 2: https://youtu.be/b9qy_8p18ks Searching for a learning object

Presentation: http://emaze.me/clark

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**References**

Kaza, Siddharth, Blair Taylor, and Kyle Sherbert. "Hello, World!—Code Responsibly." IEEE Security & Privacy 16.1 (2018): 98-100.