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Enabling Advanced Topics in Computing and Engineering Through Authentic Inquiry: A Cybersecurity Case Study

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Enabling Advanced Topics in Computing & Engineering Through Authentic Inquiry

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With the adoption of pedagogical practices such as Authentic Science and Inquiry-based projects within collegiate level classrooms, researchers focused on delivering advanced concepts investigated the level of student success in conducting authentic science during a six-week long inquiry project. Two main questions are explored: 1) do students working on self-guided, problem-based projects, engage in active inquiry? and 2) is there alignment between exemplar active inquiry projects and other assessments? This pilot research study focuses on twelve self-selected projects from a group of 33 engineering students all taking an introductory computer security course. Based on the existing body of literature surrounding Authentic Science and Authentic Inquiry the researchers performed a mixed methods study which, while focused predominately on the artifacts generated by the students also includes quantitative assessment of the artifacts themselves. Each of the five student-generated artifacts (proposal, mid-term report, final report, poster, and presentation), were analyzed for their alignment with the ten common traits of Authentic Science and Inquiry. In the preliminary analysis an unweighted percent-alignment metric was used and compared to the overall instructor-derived assessment score and an independent peer-survey. The overall results, in-line with a body of K12 research, projects with more authentic inquiry traits tend to be of a higher quality and thus higher instructor-based assessment scores. When it comes to peer-assessment scores, only half of the authentic inquiry traits are found to have significant impact outcomes – these tend to relate to humanistic properties and soft-skills – e.g. real-world impact, communication, collaboration, and enabling access to a broader community. Results seen in this work continue to motivate the re-use and adoption of pedagogical practices at the collegiate STEM level that have already been vetted by other educational communities, especially those found within the K-12 STEM educational research community.

Introduction

The most ubiquitous question throughout all of education, is a question posed by students irrespective of age, socio-economic background, aptitude or course subject is, “When are we ever going to use this?” The response that is oft provided typically references some a future class or an ultra-specific career. The struggle that K12 teachers have faced over the past few decades is well documented. What is less documented, is how collegiate level faculty can leverage the knowledge and experiences of these K12 teachers. The constantly evolving pedagogical best-known practices within K12 science, technology, engineering, and mathematics (STEM) exist to alleviate the underlying problem: students generally fail to see the relevance, cross-cutting ideas, and real world connections and applications to the material that is presented in most formal classroom settings. Why should researchers care? In one instance, 48% of all collegiate-level STEM students between 2003 and 2009 left those STEM fields by spring of 2009[1]. If for a moment, university faculty supposed that collegiate students are inherently similar to the students in K12 classrooms, then one should ask – how have K12 educational researchers and teachers changed their STEM pedagogies in ways that helped students learn? Moreover, what effective choices have the K12 students made regarding inquiry and authentic projects?

In this work, the authors focus on the of authentic inquiry within a 3-credit hour elective upper-level, undergraduate course on computer security. Authentic inquiry focuses on student-centered investigations/research/projects based on contextually-grounded real-world problems. The authors were specifically interested in the types of projects students select, the number of students working in each type of project, and the alignment of self-identified project types with project deliverables.

Problem, Purpose, and Research Question

In STEM education there has been a push, starting within K12 in the 1990's, from lecture, to hands-on, to inquiry, to authentic science learning (see literature review). While this pedagogical shift, based on prior research, is currently accepted at the K12 level, faculty at the university level still generally rely on traditional lecture formats. The problem at the university level is not in giving a project, problem, or research experience to the students (which might be the case at the K12 level) but understanding what the students do with such a task at hand. Thus, the authors of this paper asked three research questions:

- When self-selecting projects, do groups select theoretical research projects, application-centric projects, combine research and application projects, or literature survey projects with a different frequency?

- What size groups are self-selected when participating in an authentic project? And, is there a relationship between group size and project type?

- Do project proposals match end-product creation? Alternatively, what is the alignment between project proposals and the projects that they produce?

Literature Review

As far back as 1998 researchers such as Edelson were conceptualizing authentic science practices[2]. Roughly ten years later, the researchers contend, "that laboratory-based school science teaching needs to be complemented by … learning that draws on the actual world[3]." This is authentic science practice[3].

Recently, researchers are showing that authentic STEM experiences[4] include creating questions, investigating – which includes failure - and disseminating results to the community[5]. The majority of the time at the university level, undergraduate research experiences are considered authentic science experiences[6]. There is a large body of research on undergraduate research experiences[7-10]. During this time of undergraduate research experiences, there has been a push from using inquiry into authentic science and authenticity for classroom learning[11-13].

Some researchers stress the use tools such as the microscope or telescope, or activities like bioinformatics and biodiesel production, or community collaborations and summer camps as the focus for authentic science[14-23]. Tomas and Ritchie claim that integrating authentic science activities into classrooms assist students in learning how practicing scientists conduct research[24]. These types of authentic science experiences can motivate students[25].

Interestingly, sometimes the terms are combined, such as the "reflection on authentic science inquiry[26]" and "authentic science inquiry[27]." No matter which term is used, it involves doing science. Furthermore, engineering undergraduates are increasingly receiving opportunities to participate in authentic science research projects[28-31.] In 2007 53% of students in STEM fields reported guided to non-guided independent disciplinary research[28]. Obviously, there is still room for improvement in the university engineering classrooms.

Authentic science research experiences allow students to work with researchers on established projects[32] as well as new projects. Gardner, Forrester, Shumaker, Ferzli, and Shea (2015) state that "on the basis of apprenticeship models, desired learning outcomes within authentic research experiences go beyond simply the acquisition of content and tend to focus on variables related to laboratory skill attainment and career preparation. The goal of many of these programs is to provide students with experiences that scaffold their transitions into academic or industrial careers…[32]" (p 61). Preparing future engineers is what university faculty do, and they want to do it well.

Methods & Participants

This work was a quantitative study with qualitative aspects regarding student projects. The quantitative portion included counting the numbers of students in groups and counting the types of projects produced, while the qualitative aspects included investigating the artifacts (reports, posters, and presentations) that the students produced. The work described here was self-contained within a 3-credit-hour, semester long, upper-level computer security course. The course, meant as an introduction and a topic course on various aspects of computer security, was an elective with only foundational computer science courses as a pre-requisite. Course topics included: ethics, threat models, cryptography, Internet of Things (IoT) attacks & defense, binary exploits, penetration testing, malware & ransomware, authentication, network security, botnets, cyber-warfare, critical infrastructure: healthcare & transportation, and hardware security. Student deliverables during the class made up a majority of the student's assessment, these deliverables were broken down into three major categories: Synthesis, Applications, and the Active Inquiry Project. The active inquiry project itself is described in the following paragraph. A minimal number of points were assigned based on attendance and in-class participation.

The active inquiry project was introduced the first day of class during a discussion of the class' structure, objectives, and deliverables. The project consists of five major deliverables: 1) a preliminary proposal, 2) a midterm report, 3) a final report, 4) a poster, and 5) a poster presentation. While students were responsible for self-selecting their own groups, there was no established minimum or maximum group size. Rather than enforce group sizes, students advised to define their scope of work based on their group size. Students had two weeks to complete the proposal, followed by eight weeks (one of which was spring break) to complete their projects. These five specific deliverables enabled assessment of both technical and soft-skills in alignment with ABET accreditation criteria. For example, the preliminary proposal required: self-organization into groups, description of problem context, a proposed approach (plan), the definition of done / measures of success, and relevant prior-work and references. The midterm report and final report both closely followed a typical conference paper outline – instructions for the presentation of these results was intentionally limited, though the instructor provided a LaTX template. Some of the sections contained within the template included: an executive summary, an introduction with relevant references, a description of accomplishments and remaining (future) work, a list of obstacles (limitations) and workarounds, along with results and references. The poster and final presentation gave student groups a final chance at synthesizing, summarizing, and showing off their work – members of the faculty from across campus were invited and attended the poster forum which occurred during the final day of class. The poster session consisted of a 15-minute oral elevator pitch session (1 minute per group) followed by three 15-minute poster sessions where students had the opportunity to both present their posters as well as interact as an attendee. After all the work was submitted, each student submitted feedback on the division of labor within the group and highlighted any concerns – this information was used to adjust final report and poster grades.

This study used artifact evidence from student work in conjunction with quantitative data based on the same student work. The introductory cybersecurity course of 33 students consisted of two sophomores, six juniors, and 25 seniors. The class was comprised of students from the primary degree option a Bachelor of Science in Computer Science. On the first day of class, the average student clique size was 2.7 students per clique. Three of the students (9%) identified as non-traditional (adult career change, veteran). Finally, 25 students (76%) were concurrently enrolled in a required, two-semester, senior capstone course.

Analysis, Findings, and Limitations

To answer the first question, "When self-selecting projects, do students select theoretical research projects, application-centric projects, combine research and application projects, or literature survey projects with different frequency?," the authors used the initial project proposals to extract student-group self-identified project type while they used the final project deliverables to determine the actual classification of each group into one of those four categories. As shown in Table 1, there is a distinct mismatch of project type self-identification with the actual categorization. Of the twelve group projects, five (42%) self-identified as application centric projects, four (33%) self-identified as research-centric projects, while the remaining three (25%) self-identified as combined research and application projects. It is critical to note that no groups (0%) self-identified as working on a literature survey project. The authors distribution of group types includes: five (42%) application-centric projects, two (16%) research-centric projects, two (16%) research and application projects, and three (25%) literature survey projects. The mismatch occurs due to two research projects and one research and application project that were ultimately literature surveys.

Table 1: Number of groups per project type; Self-identified vs actual

Project Type	Self-Identified	Actual
Application	5	5
Research & Application	3	2
Research	4	2
Literature	0	3

To answer the second questions, "What size groups do students self-select when participating in an authentic project? Moreover, is there a relationship between group size and project type?" the authors computed:

1. the average group size irrespective of project type, and
2. the average group size based on *self-identified* and *actual* project type.

Over 12 groups and 33 students, the average group consisted of 2.7 students. More interestingly, Table 2 shows group sizes broken downs by project type. Of interest is the discrepancy in research project group sizes. Groups which *actually completed* research-centric projects had one student per group. Additionally, projects which initially *self-identified* and *actually completed* application-centric projects had more students on average (3.6 students/group) than any project type.

Table 2: Number of students per group per project type; Self-identified vs. actual

Project Type	Self-Identified	Actual
Application	3.6	3.6
Research & Application	2.3	2.5
Research	1.8	1.0
Literature Survey	0	2.3

To answer the third question, "Do student proposals match end product creation? " or stated another way, "what is the alignment between project proposals and the projects that they produce?," the authors compared project proposal objectives with the worked produced including: 1) the mid-term report, 2) the final report, 3) the poster presentation and 4) the completed actual project. The results of these four comparisons are represented as four confusion matrices (Table 3-Table 6). The column headings represent what students self-identified as their work in their proposals (predicted condition), while their actual work (true conditions) appear as rows in the table.

Notice in each table the sum of the diagonal divided the total number of groups (12) represents the overall accuracy or alignment between proposals and actual products. Green boxes highlight the individual cases along the diagonal. Alignment between proposals and mid-term products was 6/12 (50%), while alignment between the proposals and the three remaining products (final report, poster presentation, and actual completed project) was 9/12 (75%). Interestingly, however, are the elements not along the diagonal. Blue boxes represent the non-zero instances while elements that are partial matches (e.g. Research vs. Research & Application) are identified with bolded-italic numbers. While these mismatches corrected themselves after the midterm in all of the product deliverable – there still existed a fundamental disconnect in 3 of the 12 final products (what was actually accomplished) and the original proposals (Table 6). In terms of the deliverables - all but one-group (blue box, non-italic, Tables 4-5) was able to closely themselves with their original proposals realign. Notice in Table 3 that in the midterm report, five groups cited products and future work that was not in alignment with their proposals, four of which were considered extremely off-base – specifically those that claimed research activity but were only literature surveys without synthesis or any research activity.

Table 3 : Confusion Matrix between Predicted Project Type (Proposal) and True Conditions (Midterm Products Products)

		Proposal (Predicted)				
	n=12	Application	Research	Mixed	Literature Survey	
Midterm	Application	5	1	-	0	6
	Research	0	0	***1***	0	1
	Mixed	0	0	1	0	1
	Literature Survey	0	3	1	0	4
		5	4	3	0	

Table 4:Confusion Matrix between Predicted Project Type (Proposal) and True Conditions (Final Report Products)

		Proposal (Predicted)				
	n=12	Application	Research	Mixed	Literature Survey	
Final Report	Application	5	0	0	0	5
	Research	0	2	***1***	0	3
	Mixed	0	***1***	2	0	3
	Literature Survey	0	1	0	0	1
		5	4	3	0	

Table 5:Confusion Matrix between Predicted Project Type (Proposal) and True Conditions (Poster)

	n=12	Proposal (Predicted)				
		Application	Research	Mixed	Literature Survey	
Poster	Application	5	0	0	0	5
	Research	0	2	***1***	0	3
	Mixed	0	***1***	2	0	3
	Literature Survey	0	1	0	0	1
		5	4	3	0	

Table 6: Confusion Matrix between Predicted Project Type (Proposal) and True Conditions (Final Products, Actual)

	n=12	Proposal (Predicted)				
		Application	Research	Mixed	Literature Survey	
Actual	Application	**5**	0	0	0	5
	Research	0	**2**	0	0	2
	Mixed	0	0	**2**	0	2
	Literature Survey	0	2	1	**0**	3
		5	4	3	0	

Student feedback is currently limited to anecdotal comments and observations as course evaluations are not yet available to the authors. To strengthen this work, post-graduation surveys of former students and employers is critical to compare this course to prior offerings. Additionally, with only 12 groups and a total of 33 students, all from the same university and same course offering, the conclusions and implications that follow should be viewed as the result of a preliminary and focused investigation. A larger study is needed to broaden the implied scope of this work. Finally, incorporation of other existing assessment tools and strategies could aid in triangulating and validating these results within a broader context[33-35].

Conclusions and Implications

As other researchers before, the authors of this paper found that an open active inquiry project, while more challenging to assess due to the variety and complexity of the end-products, allows for student-selected differentiated learning and ownership of learning. In a upper-level elective course, focused on a breadth of topics, the ability for students to take charge in what and how they learned advanced topics enabled them to focus on a topic of their choice – hopefully one that benefits their future career objectives. The types of projects selected were surprisingly diverse and balanced. The authors found that when allowing groups to self-select a group sizes tended to be a function of perceived complexity – with application-centric projects resulting in average group size double that of research-centric projects. Remember that groups which *actually completed* research-centric projects had one student per group, and thus the first author expects to have explicit dialogues about successful projects with future classes.

Finally, when looking at the alignment between student perception of activities/products versus the actual products produced, the authors found that it is possible to identify and correct most misaligned groups (blue highlighted cells in the Tables 3-6). While ‘off-task’ or irrelevant work during an open inquiry project is possible, it is akin to employees within the work force who require extra guidance from a mentor (manager, team lead, etc.). The authors plan on using these examples of prior ‘off-task’ or irrelevant work (as non-examples) during future iterations of the course. The aim is to drive student self-reflection in determining whether or not selected tasks align with their current project goals.

In anecdotal conversations throughout the semester, the students told the first author that they felt like they learned more, and had more to talk about during interviews, from the 8-week active inquiry project than any other single experience in their collegiate career. The authors were pleasantly suprised at the passion and excitment of many of the students to continue their projects beyond the class, with almost half of the students (14) and a third of the groups (4) deciding to continue working on their project to publish in peer-reviewed academic-venues. Based on the authors’ research in K12 STEM professional developments, they will continue to develop more authentic scenarios and opportunities for their students. The authors expect this to enable students to transition from academic learners to academically trained practitioners and researchers that are capable of applying content knowledge into contextually appropriate end-products.

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