The Outcomes of Cybersecurity Competitions and Implications for Underrepresented Populations

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When I was going through [the Collegiate Cyber Defense Competition (CCDC)] I kept thinking, “Is this really what it’s like?” I’ve been working for two years now (so clearly I don’t know everything about IT or security), but I can say what I learned training for, and competing in, CCDC has helped me more in the real world than 90 percent of the stuff I learned in the classroom. —CCDC participant

Almost every cybersecurity competition organizer could share anecdotes similar to the one above. These types of statements excite employers while making cybersecurity program chairs cringe. But are these positive anecdotes enough to prompt changes to curricula and the integration of competitions into courses? What research has been conducted to unbundle the outcomes of competitions? What evidence do we have to support claims of competition advocates? And can the criticisms be validated?

In 2010, the US Department of Homeland Security Science and Technology Directorate awarded a contract to the US Cyber Challenge to develop a methodology for classifying cybersecurity challenges, games, and competitions. The project reflected the value of and need for an evidence-based approach to understanding the design of cybercompetitions. The results of this exploratory study revealed that little work to date has methodically considered:

- the challenges included in a competition, including which vulnerabilities, attack tactics, techniques and protocols, and remediation tasks are simulated during competition;
- the competencies required to perform well in each challenge;
- to what degree competition scores accurately reflect the difficulty of task performance;
- how to align or adjust competition difficulty to student competency levels to ensure participants benefit educationally and build self-efficacy as they master challenges; and
- the effectiveness of competitions in engaging students in cybersecurity—first as a game or simulation, and later as a profession.

In 2013, the Cybersecurity Competition Federation (CCF) was established with NSF support as an association of academic,
petitions are used to measure students’ gap in knowledge and skills. One educator reported that competitions can motivate students to learn. A working group on student motivation reported increased and active participation in a postchallenge discussion of solutions. Increases in knowledge and skill attributed to participation in competitions have also been reported.

Competitions can also enable differentiated learning and enriched experiences for students with diverse skill levels. One programming competition reported that students were inspired to apply their learning and improve their projects, while advanced students were incentivized with projects that challenged their abilities. Some competitors, however, report that their educational curriculum doesn’t prepare them for competitions.

One plausible explanation for these accounts is the possible disconnection between formal instructional content and competitions; however, multiple other factors are almost certainly involved. Training for cybersecurity competitions might be subject to the same knowledge transfer challenges experienced in physical education: when training is limited to isolated, repetitive practice of techniques, players have difficulty applying those techniques during actual game play. Physical education researchers recommend teaching modified versions of games to situate practice in an authentic framework. This might also contribute to better transfer of formal learning to workplace situations.

**Career Preparation Outcomes**

Several researchers conclude that competitions build awareness and interest in STEM fields by simulating professional work experiences or using directly transferrable skills, and that students participate in extracurricular activities to build a workforce-ready skill set and resume. In a study of the Science Olympiad—a team competition in which K–12 students compete in events pertaining to various scientific disciplines—76 percent of alumni stated that participation contributed to their professional accomplishments.

Regular participation in extracurricular experiences is correlated with employment and higher pay. Alexander Astin asserted that growth in knowledge and skill is expected because students chose social and extracurricular experiences connected to education. Furthermore, there’s evidence that when students choose competitions aligned to career skill sets, they’re indicating their active engagement in a profession. However, the larger body of literature on competitions, including cybersecurity competitions, doesn’t support the idea that competitions attract and retain diverse populations not already engaged with the subject area.

**Diversity Outcomes**

Competitions, by nature, rank and filter players. Unintentionally, this can start at the grade-school level, where students might be effectively excluded from competing because
they lack access to resources such as sufficient computers and educators with subject-specific training. In some STEM contest designs, only one student advances from each school. diversity is a demonstrated limitation of the Science Olympiads: competitors tend to be male, Caucasian, third-generation Americans with a high socioeconomic status. Furthermore, some school programs prioritize gifted students to improve their competition standing. In contrast, cybersecurity workforce development experts are currently calling to advance the knowledge and skills of those groups underrepresented in the field. Building awareness and engaging students underrepresented in cybersecurity careers support the goals of producing more trained workers to address the deficit in the national workforce pipeline and of increasing the field’s overall quality.

The question remains: Once we’ve built student awareness and interest, how do we support their success in competitions? Participation in extracurricular activities already predicts interest; however, are there factors that predict winning or top ranking? Although a study of Science Olympiad alumni didn’t find that age, race, or grade level correlated with finishing in the top ranks, it did identify three significant indicators: type of school, number of previous competitions attended, and number of science courses completed.

Because competition experience and content knowledge are critical factors for successful outcomes, it’s important to provide participation opportunities to diverse populations. Indeed, very different social supports and academic interventions might be appropriate when trying to invest in diversity and serve populations underrepresented in the field, including women and students of low socioeconomic status.

Top Performers and Gifted Students
The National Science Board reports that some of America’s most talented youth aren’t being identified and developed—so we’re losing many who have the potential to be the next generation of STEM innovators. Gifted students are typically curious and excellent problem solvers who demonstrate persistence when confronted with a challenge. At the same time, mathematically gifted students can disengage from formal math instruction early on because elementary school educators can’t address these students’ intuitive understanding of algorithms. Students labeled as gifted might also avoid the pressure of competing against other gifted students because they’re discouraged when they discover that they’re “not the best.” But, ultimately, competitions are one way to educate gifted students: a study on math, chemistry, and physics Olympiad alumni concluded that such competitions effectively advanced their STEM talents.

Low Socioeconomic Status, High Risk
“Students learn by becoming involved.” On college campuses, however, first-generation college students aren’t likely to join clubs or organizations—despite strong evidence that such involvement is associated with positive outcomes for this population. Students who were involved in clubs during high school or who live or work on campus are more likely to participate in clubs during college. Faculty involvement can also increase student participation. Research suggests that supportive relationships and youth programs let high-risk students overcome obstacles to academic success. Cybersecurity clubs and competitions can succeed in broadening diversity in the workforce pipeline only if recruitment and outreach include long-term interventions such as supportive relationships and early involvement with campus faculty and students.

Gender
Women make up only 11 percent of the information security workforce. A case study investigating the Israeli National Computer Science (CS) Olympiad reported 15 percent female participation in early rounds of the competition, but despite targeted recruitment and participation in advanced training, no woman has ever reached the final. Such attrition is especially startling in light of the following trends: women are more likely than men to enroll and graduate from college and to participate in nonathletic extracurricular activities, and just as likely to use technology such as computers, tablets, and smartphones. Adding to the problem’s complexity, it’s been reported that almost 50 percent of the middle school students in technology-related classes in the US are female, a number that drops to only 17.7 percent by high school. Therefore, supporting gender equity in competitions requires addressing a larger systemic problem that starts before or during middle school. It’s been posited that women don’t see the social benefit of a perceived solitary occupation. Others theorize that women experience low self-confidence due to lack of experience or role models. Successful strategies to help engage more women in cybersecurity competitions will involve providing girls with learning experiences and extracurricular activities that build self-efficacy and career engagement before they leave middle school.

Design Considerations
Current cybersecurity competitions claim to offer experiences ranging from novice to expert. Players can find competitions that focus
on almost any cybersecurity field: offense, defense, cryptography, forensics, reversing, programming, and any combinations of these. Some competitions are designed for fun or prizes, others for recruitment and identification of talent, and still others for reputation building. The (unadvertised) challenge for players is to find competitions that align with their interests, capabilities, and goals. Existing literature documents several design considerations that would support engagement in competitions and be useful for developing the skills required for the next level of competition. For example, novice coaches and students have frequent questions and require additional support.

One programming-competition developer suggests that organizers give participants the challenge packets two weeks before the competition. This lets participants determine whether they have the adequate skills and interested team members. It’s also been suggested that novice competitors replicate best practice in realistic simulations. Several competitions have been designed to help students apply the thoughtful process of planning and implementing security while maintaining the efficiency of network services. This realistic representation is thought to prepare competitors to meet their future employers’ needs; however, it might be too complex for novice players.

Novice players also require careful alignment of challenge difficulty to their existing competency. Game balance is achieved when a competition doesn’t exceed the players’ capabilities. The National Cyber League has developed an innovative approach to providing a competition for players of all skill levels: before individual and team competitions, a mandatory preseason competition is held during which players are bracketed by score, so novice players compete against other novice players, and so on. This method has resulted in a smaller percentage of dropouts among novice populations. Identifying a player’s entry-level competency might be key to successful outcomes in cybersecurity competitions. Karen Cooper found that simulation systems led to engagement only when the participant’s skill level was sufficiently high. This finding is corroborated by a small exploratory study that found that competitions might be disengaging to novice learners.

Thus, competitions might be effective only for students with existing skill sets that closely match competition requirements. CCF research into competition outcomes determined that competitions used in education require special considerations. Frances Karnes and Tracy Riley list criteria that educators might consider when selecting competitions for their students. In particular, if competitions are to be used in an educational setting, the activities must align with official curriculum. Competitions should be designed with the outcomes for each activity clearly stated. This will help teachers justify inclusion of the competition. Clearly stated objectives also help teachers choose activities that are relevant and interesting to their students.

Limitations
Up to this point, we’ve discussed the promise of competitions. They reward accomplishments in STEM fields and are a tangible expression of STEM’s importance and value. Increased program enrollment has also been reported as individuals and teams win competitions. However, the most probable explanation for increased enrollment is the likelihood that competition-related extracurricular programs attract students who are already engaged with the STEM fields and likely to enroll in STEM programs in college.

What’s more, the competition literature is filled with unsupported claims of engagement and motivation for learning in classrooms. Anecdotal claims might be connected to any “break from their usual routine” rather than to the competition itself. Further research is required because some case studies of immersive educational simulations support the view that hands-on activities engage the participant and, in so doing, facilitate situational learning and transfer of skills to the real world. Figure 1 lists future research directions for improving the design of cybersecurity competitions.

Although there’s been some research on the outcomes and efforts to support engagement of underrepresented populations in cybersecurity competitions, much work remains. For example, most training for cybersecurity competitions occurs through extracurricular activities; so, there’s an opportunity to build self-efficacy among underrepresented students by incorporating competitions or challenges into the standard K–12 curriculum by providing hands-on tutorials that let students learn independently or in teams using any Internet-capable computer. We must continue to fund and conduct research that determines cybersecurity competitions’ effect on students’ awareness.
of cybersecurity careers and their ability to build confidence and self-efficacy as well as research to establish a developmental pathway of cybersecurity-based activities that support skill growth. ■

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Figure 1. The factors listed can limit cybersecurity competitions’ effectiveness in STEM (science, technology, engineering, and mathematics) outreach and are thus potential areas for future research.


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