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[1]

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,

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industry, and government organizations with a common interest in supporting cybersecurity competitions and the competitors they serve. This federation communicates with and promotes cybersecurity competitions to increase awareness, provide guidance on ethical standards, build a common understanding of diverse competition tasks, support those who oversee activities and competitions, and create a developmental pathway using activities that aid the growth of cybersecurity skills. During the three-year grant period, CCF members conducted research to understand the players and outcomes of cybersecurity competitions to identify the needs of competition stakeholders.

Here, we reflect on cybersecurity competitions, drawing primarily from CCF workshops, literature reviews, and reported outcomes of similar STEM (science, technology, engineering, and mathematics) competitions. In particular, we consider those studies relevant to gifted students, females, and low-income and high-risk groups.

Learning Outcomes

Anecdotal evidence, such as the rapid increase in the number and diversity of competitions, shows that students believe competitions can be fun. And there's further complementary evidence that competitions can motivate students to learn. Whether to fulfill formal learning or personal development goals, players might actively connect competition experiences to practice techniques or apply the knowledge they've acquired. Learning outcomes, however, are implicit even when players appear primarily motivated by fun: as they're exposed to different challenges, players expand their ability to apply what they know to solve new problems.

In some STEM programs, competitions are used to measure student growth or as capstone projects. Some instructors use competitions formatively to identify individual students' gaps in knowledge and skills. One educator reported the metacognitive possibilities of competitions: as students work in teams, they're asked to provide one another feedback as well as reflect on their own abilities.[2]

Competitions offer problem-based learning in authentic situations and represent a student-centered approach to knowledge development. A working group on student motivation reported increased and active participation in a postchallenge discussion of solutions.[3] Increases in knowledge and skill attributed to participation in competitions have also been reported.[4] Competitions that are modeled on standardized tests have been used to raise student scores on college entrance exams.[5] Furthermore, there's evidence that team-based competitions support the development of "soft skills" such as teamwork, critical thinking, and communication.[3]

Competitions can also enable differentiated learning and enriched experiences for students with diverse skill levels. One programming competition reported that novices 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.[1]

One plausible explanation for these accounts is the possible disconnect 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.[6] 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,[7] and that students participate in extracurricular activities to build a workforce-ready skill set and resume.[8] 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.[9]

Regular participation in extracurricular experiences is correlated with employment and higher pay.[10] Alexander Astin asserted that growth in knowledge and skill is expected because students chose social and extracurricular experiences connected to education.[11] Furthermore, there's evidence that when players choose competitions aligned to career skill sets, they're indicating their active engagement in a profession.[12] 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.[5,9] Diversity is a demonstrated limitation of the Science Olympiads: competitors tend to be male, Caucasian, third-generation Americans with a high socioeconomic status.[9] Furthermore, some school programs prioritize gifted students to improve their competition standing.[7] In contrast, cybersecurity workforce development experts are currently calling to advance the knowledge and skills of those groups underrepresented in the field.[13] 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.[14]

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.[15] 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.[9] 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."[5] 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.[9]

Low Socioeconomic Status, High Risk

"Students learn by becoming involved."[11] 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.[8] 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.[8] Research suggests that supportive relationships and youth programs let high-risk students overcome obstacles to academic success.[16] 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.[17] 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.[18] 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.[19] 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.[20] Others theorize that women experience low self-confidence due to lack of experience or role models.[16] 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.[21] 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.[22]

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.[23] This finding is corroborated by a small exploratory study that found that competitions might be disengaging to novice learners.[24] 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.[7] 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.

There's an opportunity to build underrepresented students' self-efficacy by incorporating cybersecurity competitions into the standard K–12 curriculum.

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.[4] 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"[25] rather than to the competition itself.[26] 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.[27] 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

Factors studied in cybersecurity competitions:

- lack of opportunities for novices,
- high attrition, and
- lack of alignment to curricular outcomes.

Unstudied factors, suggested by STEM studies:

- good correlation to professional success,
- rankings' effect on creating incentives to promote or advantage gifted populations, and
- self-selection for participation by second- or third-generation college students.

Implications for future efforts in designing and assessing competitions:

- alignment of winning and scoring with another intended, measurable outcome;
- programs focused on establishing mentorship networks and building self-efficacy;
- programs serving students before or during middle school;
- studies directly paralleling those from STEM competitions, for example, alumni studies, to see whether lessons learned, in fact, translate to cybersecurity competitions; and
- studies validating claims about engagement and learning.

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.

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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References

1. P. Pusey, C. O'Brien, and L. Lightner, "National CyberWatch Center Preparing for the Collegiate Cyber Defense Competition (CCDC): A Guide for New Teams and Recommendations for Experienced Players," 2014; scout.wisc.edu/cyberwatch/downloads/62/NCC_Press_How_To_Prepare_For_the_CCDC.pdf.
2. A. Conklin, "The Use of a Collegiate Cyber Defense Competition in Information Security Education," *Proc. 2nd Ann. Conf. Information Security Curriculum Development* (InfoSecCD 05), 2005, pp. 16–18.
3. J. Carter et al., "ITiCSE 2011 Working Group Report Motivating All Our Students," *Proc. 16th Ann. Conf. Innovations and Technology in Computer Science Education* (ITiCSE 11), 2011, pp. 5–8.
4. J. Rursch, A. Luse, and D. Jacobson, "IT-Adventures: A Program to Spark IT Interest in High School Students Using Inquiry-Based Learning with Cyber Defense, Game Design, and Robotics," *IEEE Trans. Education*, vol. 53, no. 1, 2010, pp. 71–79.
5. A. Trotter, "Competing for Competence," *Education Week*, vol. 27, no. 30, 2008, pp. 36–38.
6. P. Werner, R. Thorpe, and D. Bunker, "Teaching Games for Understanding: Evolution of a Model," *J. Physical Education, Recreation & Dance*, vol. 67, no. 1, 1996, pp. 28–33.
7. F.A. Karnes and T.L. Riley, "Developing an Early Passion for Science through Competitions," *Gifted Child Today*, vol. 22, no. 3, 1999, pp. 34–36.
8. K.F. Case, "A Gendered Perspective on Student Involvement in Collegiate Clubs and Organizations in Christian Higher Education," *Christian Higher Education*, vol. 10, nos. 3–4, 2011, pp. 166–195.
9. J.R. Campbell and H.J. Walberg, "Olympiad Studies: Competitions Provide Alternatives to Developing Talents that Serve National Interests," *Roeper Rev.*, vol. 33, no. 1, 2010, pp. 8–17.
10. D.D. Albrecht, D.S. Carpenter, and S.A. Sivo, "The Effect of College Activities and Grades on Job Placement Potential," *NASPA J.*, vol. 31, no. 4, 1994, pp. 290–297.
11. A.W. Astin, "Student Involvement: A Developmental Theory for Higher Education," *J. College Student Personnel*, vol. 25, no. 4, 1984, pp. 297–308.
12. M. Prenzel, "The Selective Persistence of Interest," *The Role of Interest in Learning and Development*, K.A. Renninger, S. Hidi, and A. Krapp, eds., Lawrence Erlbaum Associates, 1992, pp. 71–98.
13. "National Initiative for Cyber-Security Education: Strategic Plan," National Initiative for CyberSecurity Education, 2012; csrc.nist.gov/nice/documents/nicestratplan/nice-strategic-plan_sep2012.pdf.
14. W. Baird, "Correlates of Student Performance in the Science Olympiad: The Test of Integrated Process Skills and Other Variables," *Proc. Ann. Meeting National Assoc. Research in Science Teaching*, 1989; files.eric.ed.gov/fulltext/ED305248.pdf.
15. *Preparing the Next Generation of STEM Innovators: Identifying and Developing Our Nation's Human*

Capital, report NSB 10-33, National Science Foundation, 2010.
16. T.G. Zimmerman et al., "Why Latino High School Students Select Computer Science as a Major: Analysis of a Success Story," *ACM Trans. Computing Education*, vol. 11, no. 2, 2011, p. 10.
17. *Agents of Change: Women in the Information Security Profession: The (ISC)² Global Information Security Workforce Subreport*, Frost & Sullivan, 2013; www.isc2cares.org/uploadedFiles/wwwisc2cares.org/Content/Women-in-the-Information-Security-Profession-GISWS-Subreport.pdf.
18. O. Sagy and O. Hazzan, "Diversity in Excellence Fostering Programs: The Case of the Informatics Olympiad," *J. Computers in Mathematics and Science Teaching*, vol. 26, no. 3, 2007, pp. 233–253.
19. C.R. Mitts, "Gender Preferences in Technology Student Association Competitions," *J. Technology Education*, vol. 19, no. 2, 2008, pp. 45–59.
20. P. Doerschuk, J. Liu, and J. Mann, "Pilot Summer Camps in Computing for Middle School Girls: From Organization through Assessment," *ACM SIGCSE Bull.*, vol. 39, no. 3, 2007, pp. 4–8.
21. L. Sherrell and L. McCauley, "A Programming Competition for High School Students Emphasizing Process," *Proc. 2nd Ann. Conf. Midsouth College Computing* (MSCCC 04), 2004, pp. 173–182.
22. C. O'Brien, P. Pusey, and J. Jones, "Competition as Curriculum: Why Competitions Will Work in Your Field," *Proc. High Impact Technology Exchange Conf.: Educating America's Technical Workforce* (HI-TEC 14), 2014.
23. K. Cooper, "Go with the Flow: Engagement and Learning in Second Life," *Proc. Spring Simulation Multi Conf.* (SpringSim 10), 2010; doi:10.1145/1878537.1878578.
24. D.H. Tobey, P. Pusey, and D. Burley, "Engaging Learners in Cybersecurity Careers: Lessons from the Launch of the National Cyber League," *ACM Inroads*, vol. 5, no. 1, 2014, pp. 53–56.
25. A. Rosenbloom, "Running a Programming Contest in an Introductory Computer Science Course," *Proc. 14th Ann. ACM SIGCSE Conf. Innovation and Technology in Computer Science Education* (ITiCSE 09), 2009, p. 347.
26. R.E. Clark, "Reconsidering Research on Learning from Media," *Rev. Educational Research*, vol. 53, no. 4, 1983, pp. 445–459.
27. C. Dede, "Immersive Interfaces for Engagement and Learning," *Science*, vol. 323, no. 5910, 2009, pp. 66–69.

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