Design, Implementation, and Assessment of Synchronized Worldwide Online Robotics Competitions for Engineering and Computing Education

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***Abstract*—The work presented in this Full Paper is categorized as Innovative Practice, as per FIE guidelines. Robofest is a worldwide robotics competition program for students in 4th-12th grade and college. Student teams design, construct, and program their autonomous robots in a variety of competition categories. In the 2019-2020 academic year, due to the COVID-19 pandemic, we designed an innovative and novel online robotics competition format using Zoom Webinar tools rather than cancelling the world championship competition. The purpose of this paper is to show how we designed, implemented synchronized online robotics competitions, and to analyze the results and efficacy of the Robofest Online World championships (ROWC). One hundred and fifty-three teams comprising of 360 students competed in three age divisions and six categories held weekends from Aug. 28 through Oct. 10, 2020. Most teams set up playing fields at home and we trained judges online prior to the competitions. We sent the description of an unknown game ending task and unknown playing field factors to local volunteer judges at the same time just before the 30-minute work time on the competition day. After checking to make sure that all the teams were ready to play, we sent the game start signal to all the teams at the same time through Zoom. The local judges scored the runs and submitted videos to the Robofest office for score verification. Robofest office staff also proctored the competitions through Zoom screens for fair competition results and maximum learning opportunities. It was an innovative practice of using online conference tools to organize the world's first unique "synchronized" online autonomous robotics competitions for engineering and computing education. Anonymous coach & judge survey results after the ROWC showed that the satisfaction rate was better than the in-person competition surveys of previous years. Additionally, 95% of students surveyed after the ROWC exposure said that they would now consider a career involving STEM versus 91% of students surveyed after the 2019 in-person competitions.**

Keywords—online robotics competition, autonomous robotics, computational thinking, computer science and engineering education, virtual robotics, online learning environment, STEM education, synchronized online competition, online competition methodologies

I. Introduction

Educational robotics improves students' computational thinking and STEM attitudes [1, 2]. Robofest [3, 4, 5, 6, 7] is an autonomous robotics competition for 4th ~ 12th grade and college students with a variety of competition categories for STEM plus computer science learning as shown in Tables I & II. Robofest's mission is to generate excitement & interest among young people for Science, Computer Science, Technology, Engineering, and Mathematics (STEM), to develop soft skills such as teamwork, creative thinking, communication and problem solving, and to prepare them to excel in higher education and technological careers.

Unlike other popular K-12 robot competitions that limit the student's robots to specific kits and parts, Robofest allows the student to use any robotics system, programming languages, parts, materials, or even custom electronics. Another notable difference is that Robofest Game style competitions shown in Table I have Unknown Tasks and Factors (UTFs) that students must solve or adjust their codes within a 30 minute work-time without any external help. In Game style competitions, winners are determined based on fixed rules.

TABLE I. GAME STYLE COMPETITION CATEGORIES

Category ***(difficulty level)***	**Challenge Theme**	**Unknown Tasks**	**Unknown Factors**
Game *(Intermediate-Advanced)*	Announced annually	Some tasks are unknown	Playing field parameters and/or properties
BottleSumo *(Beginners)*	Fixed. Be the first robot to push intentionally a bottle off the table OR be the last robot remaining on the table	How to start is unknown	Location of bottle; Playing field properties; Location of opponent robot
UMC *(Intermediate-Advanced)*	Changes annually and completely unknown till the competition day	Completely unknown	Completely unknown

Since competitions with fixed rules may limit students' imagination and creativity, Robofest has offered science fair like Exhibition style competitions as shown in Table II. Students have complete freedom in Exhibition style competitions to create interactive and intelligent robotics projects.

Figure 1 shows the number of student participants since 2000 till 2020. Due to the global pandemic, we had a sharp

Robofest major sponsors include: DENSO, Michigan Council of Women in Technology Foundation, Robomatter Inc., National Defense Industrial Association Michigan Chapter, IEEE Southeastern Michigan Section, SoarTech, Realtime Technologies, and IBM.

decrease in the number in 2020. A total of 1,476 students in 549 teams including both in-person and online teams participated from 13 countries and 5 US States. The average Robofest team size in 2020 was 2.7, down from 3.0 in 2019.

TABLE II. EXHIBITION STYLE COMPETITION CATEGORIES

Category ***(difficulty level)***	**Project Theme**	**Winner Decision**	**Unknown Factor**
Exhibition *(Intermediate-Advanced)*	Any. Widely Open	By a panel of Judges using a rubric	Venue lighting condition
RoboArts [8] *(Intermediate-Advanced)*	Visual and/or Performing Arts		
RoboMed *(Advanced)*	Medical or healthcare related		

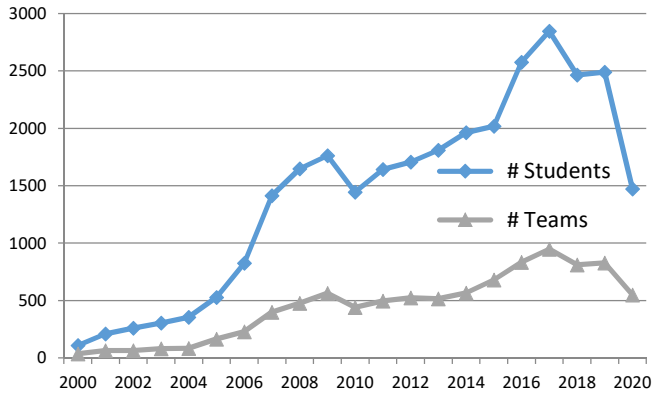

Fig. 1. Number of Robofest student participants and teams since 2000. In 2020, the total number of in-person teams was 279 before the lockdown in March. The total number of online competition teams was 270.

During the 2019-2020 academic year, due to the COVID-19 global pandemic, we had to halt all the qualifying competitions in March. For the world championship, rather than canceling it, we decided to create a new modality in competition-based learning using online conference tools after a coach survey. 93% of coaches supported or somewhat supported the idea of online competitions as shown in Figure 2.

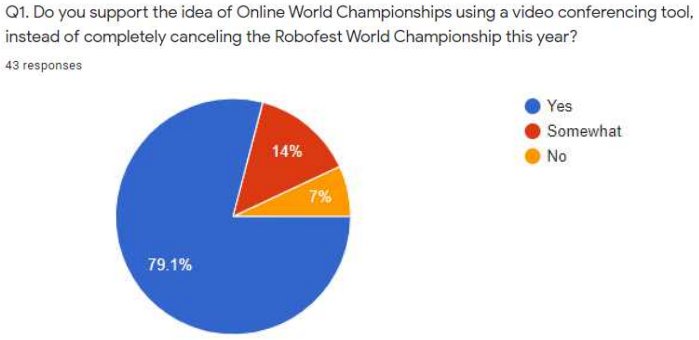

Fig. 2. Results of coach survey to ask if they support online world championships. Completed on April 30, 2020

During and after the pandemic, online learning gets a growing acceptance [9]. The purpose of this article is to describe how we designed, implemented synchronized live online robotics competitions, and to analyze the results of the Robofest Online World championships (ROWC) and the efficacy of online learning through robotics competitions.

We had the following two basic research questions when we started the project:

1) Will coaches, teachers, and students be satisfied with the online competition format?
2) Will the online competition be effective in motivating students to learn STEM subjects and attracting into STEM careers?

II. TOP-LEVEL KEY DECISIONS TO DESIGN ONLINE COMPETITIONS

First of all, we had to decide the following top-level considerations to design and implement the ROWC.

A. Name: Online or Virtual

People are using the word either "online" or "virtual" if the events, meetings, or conferences are using the Internet, not in-person. However, in robotics, "virtual" robots mean the robots in a simulation environment [10, 11, 12]. Therefore we decided to use the word "online", instead of virtual, since Robofest, using real physical robots, does not use any robotic simulators for competitions.

B. Synchronized or In-sequence

Synchronous robotics competitions in the virtual world were held in real-time from geographically dispersed sites across Nebraska as reported in [12]. Here we explain why we needed synchronized, not in-sequence competitions and how we designed them.

Robofest UTF's are like robotics exam questions. Robofest Game competitions must be held at the same time mainly because the UTF is unveiled at the same time for every team. Otherwise, if we run robots in-sequence based on predetermined orders at scheduled time, it will be unfair since teams who compete late may have longer time to solve the UTF problems. After 30 minutes of work-time, every team all around the world must impound the team's robot at the same time for fair competitions. Another important factor to choose synchronized method instead of in-sequence was to shorten the competition turnaround time.

For Exhibition style competitions, we could design completely in-sequence competitions in which teams just come to present at scheduled time over multiple days. In that case teams do not need to join at the same time slot. However, since teams often learn from other teams, we designed Exhibition style competitions in such a way that teams were synchronized to meet, present their projects, and interact with other teams by asking questions as if the events are in-person.

C. Single team or multiple teams at one location

To comply with each country's COVID-19 social distancing related laws, rules, ordinances, and recommendations, we asked that only a single team meet at each competition location. Additionally, if there are multiple Zoom devices with speakers

at one location, the audio noise echoes making it difficult to hear.

D. Competition time and duration

Since we decided to have synchronized events, to find a time slot that can be possible to have competition for every country involved was not easy. Our basic rules were that competitions shall not start after 9 p.m. or before 5 a.m. for every time zone. We colored cells that violate the rule in orange as shown in Figure 3. We chose the row in the center that had minimum violation. According to the row, the competition begins at 5am in the USA west coast time (PDT) and 9 p.m. in South Korea. Unfortunately, teams in Hawaii had to begin competition at 2 a.m. As a result, no teams from Hawaii participated in 2020. In order to finish the competition before midnight in Korea, we also decided to plan the duration of the competition for a maximum 3 hours.

Member Countries /Regions	USA Hawaii	USA WEST	Colombia, Ecuador, Mexico City, USA Central	USA EAST	Canada NS	Ghana, Morocco, Sierra Leone	Nigeria	Egypt, Malawi, S. Africa, Zimbabwe	Ethiopia, Bahrain, Greece, Kenya, Qatar, Saudi	UAE	India	China Beij., Hong Kong, Macau, Philippines, Taiwan	S. Korea
GMT	-10	-7	-5	-4	-3	0	1	2	3	4	5.5	8	9
Time in 24 hours	15	18	20	21	22	1	2	3	4	5	6.5	9	10
	16	19	21	22	23	2	3	4	5	6	7.5	10	11
	17	20	22	23	24	3	4	5	6	7	8.5	11	12
	18	21	23	24	1	4	5	6	7	8	9.5	12	13
	19	22	24	1	2	5	6	7	8	9	10.5	13	14
	20	23	1	2	3	6	7	8	9	10	11.5	14	15
	21	24	2	3	4	7	8	9	10	11	12.5	15	16
	22	1	3	4	5	8	9	10	11	12	13.5	16	17
	23	2	4	5	6	9	10	11	12	13	14.5	17	18
	24	3	5	6	7	10	11	12	13	14	15.5	18	19
	1	4	6	7	8	11	12	13	14	15	16.5	19	20
	2	5	7	8	9	12	13	14	15	16	17.5	20	21
	3	6	8	9	10	13	14	15	16	17	18.5	21	22
	4	7	9	10	11	14	15	16	17	18	19.5	22	23
	5	8	10	11	12	15	16	17	18	19	20.5	23	24
	6	9	11	12	13	16	17	18	19	20	21.5	24	1
	7	10	12	13	14	17	18	19	20	21	22.5	1	2
	8	11	13	14	15	18	19	20	21	22	23.5	2	3
	9	12	14	15	16	19	20	21	22	23	24.5	3	4
	10	13	15	16	17	20	21	22	23	24	1.5	4	5
	11	14	16	17	18	21	22	23	24	1	2.5	5	6
	12	15	17	18	19	22	23	24	1	2	3.5	6	7
	13	16	18	19	20	23	24	1	2	3	4.5	7	8
	14	17	19	20	21	24	1	2	3	4	5.5	8	9

Fig. 3. Table to determine the optimized start time for all participating countries. Each cell represents the time for each time zone.

E. Online Video Conferencing Tool

We chose Zoom Webinar platform different from Zoom Meetings, since it provides functions for large events such as view only audience, YouTube or Facebook live streaming, and spotlighting panelists. We purchased an account for 500 total connections. We assigned one Zoom Webinar "panelist" account for each team.

III. DESIGN OF THE ROWC

The first design consideration for the online competition was the pre-meeting. Teams, Coaches, and Local Judges were required to attend a pre-meeting, 2 days prior to the competition day for each category. Each team must be ready to demo & dry-run robots. This means each team must have a playing field and means for video conferencing (camera & microphone). We assigned one Zoom login for each team competition location. Robofest office developed a check-list for each category and checks Zoom setup, practices the use of Zoom Webinar, the playing field setup, and trains Local Game Judges. Robofest maintained Zoom office hours for teams, coaches, and Judges who could not attend the scheduled pre-meeting. We learned that the pre-meeting was essential for online competitions.

Since Robofest's Game Style competitions are different from Exhibition style competitions, even if all the teams are meeting at the same time in both styles, we developed two sets of competition rules and guidelines.

Game Style Competition Design

Figure 4 shows the environment of Game Style competitions (Game, BottleSumo Time Trial, Unknown Mission Challenge) using the Zoom Webinar platform. Head-to-head BottleSumo competitions converted to a "Time Trial" only competition to be the fastest robot to push all the bottles off the table & survive. The concept is like Judges and teams are on the stage and Webinar attendees are seated in view-only seats in a virtual auditorium. The events on the stage are broadcasted (streamed) live on Facebook.

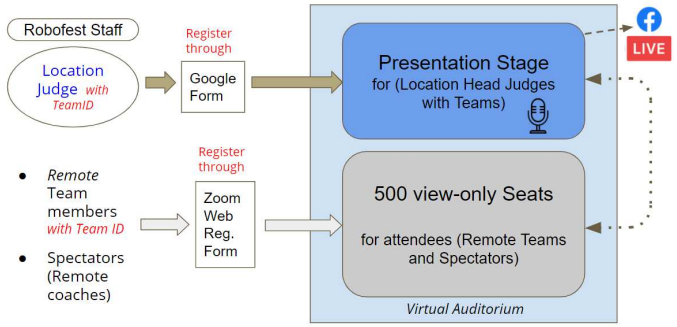

Fig. 4. Game style competition environment with Zoom Webinar

A Judge at a competition location is called "Location Judge". Three Location Judges were recommended for each competition location. Their main roles are to (1) enforce UTF to the team after getting it via Zoom as well as emails (2) score Games based on all the Game rules (3) record videos of official competition runs then send them to Robofest Office as shown in Figure 5. Since the integrity of Location Judges is very important for fair competitions, we first require the approval of Robofest National Director. They are to recite the Location Judge's Oath shown in Figure 6 during the opening. Students' cooperation is also essential. Students recited Contestant Pledge in Figure 7 to confirm all the rules.

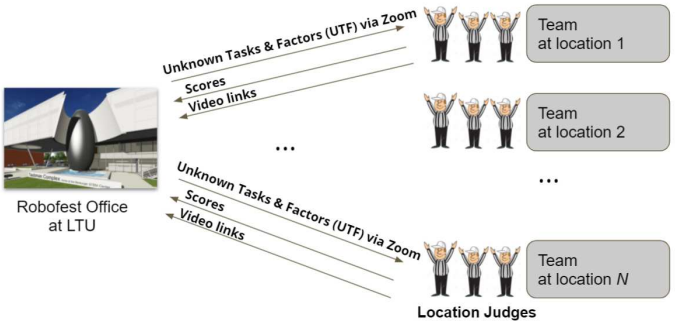

Fig. 5. Game style judging

On my honor, I agree to serve today as an official location judge of a Robofest online World Championship in a completely fair and impartial manner for this global event.

I personally commit to this responsibility with no previous conflicts of interest, direct relationship to the teams, or pre-determined expectations for the outcome of the competition.

I understand the sprint of Robofest - that students solve problems and adult coaches/parents are not allowed to assist during the competition.

I have read the rules carefully, understand them clearly, and will make my evaluations based on the rules.

After the competition, I will submit videos and scores with integrity.

Fig. 6. Location judge's oath

As a Robofest team member, I understand that the focus of Robofest is about learning through competition.

I will show personal integrity by honoring all Robofest rules, valuing fair competition and respecting judges and all other participants.

I will do my own work. I will NOT receive outside help from coaches, mentors, electronic devices or other sources during competitions and I will strictly follow impounding procedures.

I pledge make the first Online Robofest 2020 great by upholding the Spirit of Robofest.

Fig. 7. Contestant pledge

Figure 8 shows suggested setup for competition locations. Two devices with microphone and camera are required for each location. One is for Zoom and the other is for video recording of official runs. Parents are supposed to leave the location. They can join the webinar as spectators or watch a livestream on Facebook Live outside the location.

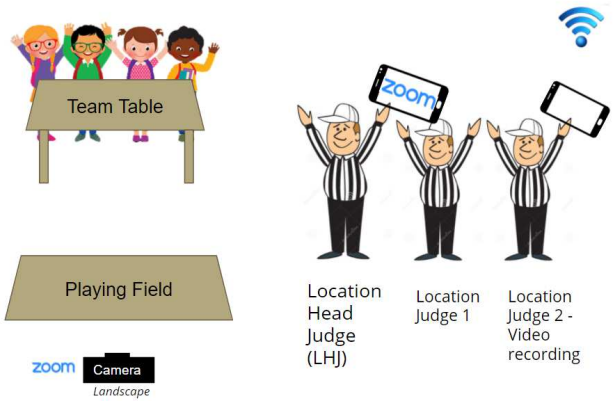

Fig. 8. Game style Location setup

Exhibition Style Competition Design

Figure 9 depicts the environment of Exhibition Style competitions (Exhibition, RoboArts, RoboMed) using the Zoom Webinar platform. Judges are on the stage all the time. Each team is moved to the stage to present. Judges can ask questions directly to the team. Attendees can ask questions via Zoom Q&A function.

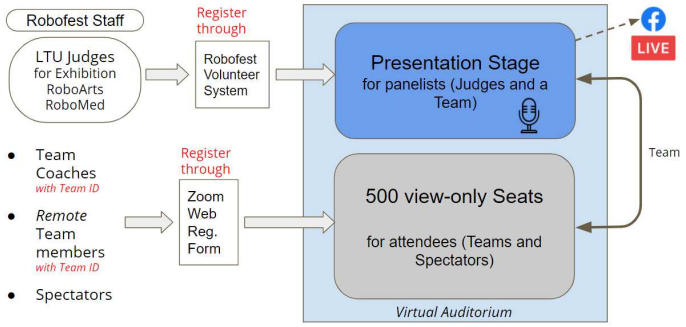

Fig. 9. Exhibition style competition environment with Zoom Webinar

A panel of judges are all appointed by Robofest office. Code Inspector(s) will recommend points for programming. Each team is required to submit pre-recorded 4-minute video and source code files to the judges via Robofest office. Judges are required to watch the videos prior to the event to be familiar with the projects they are judging. Winners will be determined based on the pre-video, live online presentation and robot demonstrations, source code inspection results, and live questions and answers using a rubric for each category. The concept of Exhibition style judging is depicted in Figure 10.

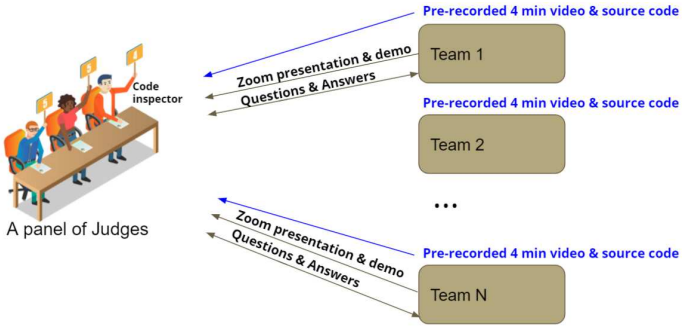

Fig. 10. Exhibition style judging

Figure 11 shows suggested Exhibition style Location setup. Team Coach is in charge of setting up the exhibition table and Zoom camera. If teams plan to "share screen" during their presentation using Zoom, a request must be submitted to Robofest Office prior to the pre-meeting. Parents are encouraged to leave the location like Game style competitions.

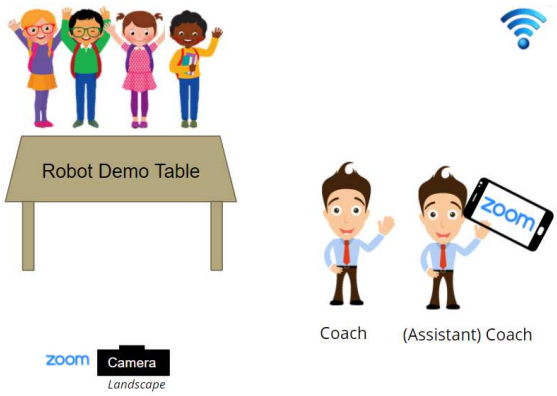

Fig. 11. Exhibition style Location setup

IV. Results of Online Competitions

Before the official ROWC, we had 3 mock competitions as well as some remaining qualifying competitions to validate the online competition methods and gain experience. A total of 117 teams with 246 students participated in these competitions from May till August in 2020. Official ROWC was held from Aug 28 to Oct 10 as shown in Table III. The total number of teams and students who participated in ROWC were 153 and 360, respectively.

Most online competition teams set up playing fields at home and we trained location judges online during the pre-meetings prior to the competitions. For Game style competitions, we sent the description of an unknown game ending task and unknown playing field factors to local judges at the same time just before the 30-minute work time on the competition day. After checking to make sure that all the teams are ready to run their robots, we sent the game start signal verbally to all the teams at the same time through Zoom. The local judges scored the runs and submitted videos that must include the game-start signal to LTU for score verification. Robofest office staff also proctored the competitions through Zoom screens for fair competition results and maximum learning opportunities. Winners of all the competition categories were announced on October 17. We had enough time to verify all the scores and videos before the announcement.

TABLE III. ROWC Numbers For Each Category

	# Coaches	# Teams	# Students
UMC Jr, Friday, Aug 28	8	12	23
UMC Sr, Saturday, Aug 29	9	11	21
RoboArts, Friday, Sep 11	11	11	37
RoboMed, Saturday, Sep 12	10	10	28
Exhibition Jr, Sep 18	9	9	24
Exhibition Sr, Sep 19	7	7	20
BottleSumo Time Trial Jr, Friday, Sep 25	14	17	34
BottleSumo Time Trial Sr, Saturday, Sep 26	19	31	64
Game Jr, Friday, Oct 9	15	23	47
Game Sr, Saturday, Oct 10	19	22	62
Total	**121**	**153**	**360**

Figure 12 shows a snapshot example of online Senior Game competition held on Oct. 10. ROWC award winners, highlight videos, programs, and judge bios for each competition category can be accessed on the archived ROWC webpage at [13].

Fig. 12. A snapshot example of online Senior Game competition held on Oct. 10th.

V. Assessment Results

A pre-survey was sent out to each team coach when the team was registered. After the World Championship was completed in October 2020, a post-assessment survey was sent out to the team coaches. 114 students participated anonymously in the pre-survey and 91 students in the post survey. The summary of 2020 assessment results with two recent years is shown in Figures 13 and 14. The assessment data of 2018 and 2019 years are from [14] and [15]. Detailed assessment results of 2020 can be found in the 2020 Annual Report [16].

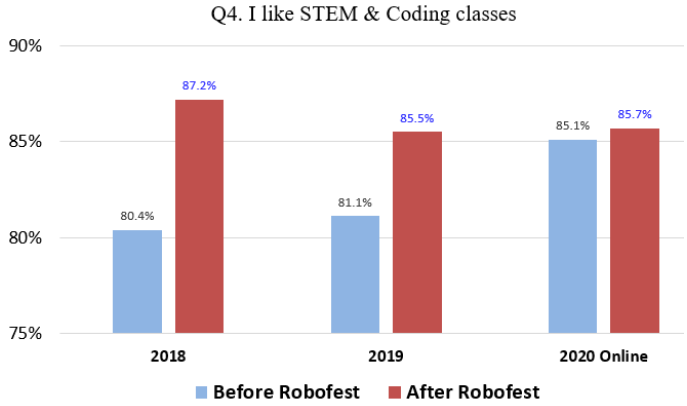

Fig. 13. Pre and post survey results for "Q4. I like STEM and/or Coding related classes" from 2018 to 2020.

Survey results in Figure 13 shows that 85.7% of Robofest 2020 students like STEM & Coding classes after the 2020 Robofest online competition experience. The percentage increase was 0.6% from 85.1%. The increase was smaller than previous years. We think that was due to the fact most ROWC students liked STEM subjects already before joining in Robofest. We had unprecedented high dropout rate (see Table IV, row 2) and we had just a few rookie teams.

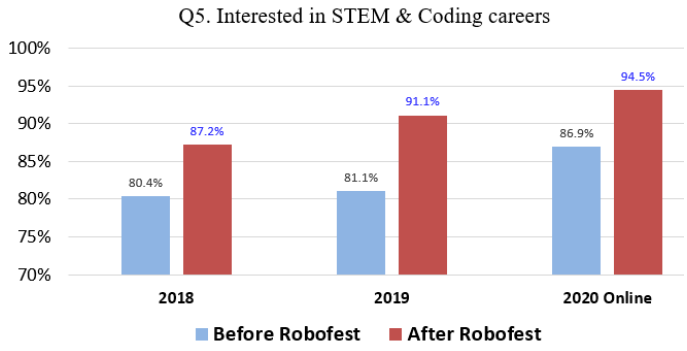

Fig. 14. Pre and post survey results for "Q5. Are you interested in a career involving STEM and/or coding?" from 2018 to 2020.

94.5% of students surveyed after the ROWC exposure said that they would now consider a career involving STEM versus 91.1% of students surveyed after the 2019 in-person competitions. The percentage of the online year 2020 was the highest in 3 years as shown in Figure 14.

The following TABLE IV compares key program evaluation criteria including the above two numbers for 2019 and 2020 years.

TABLE IV. COMPARISON OF EVALUATION DATA IN 2 RECENT YEARS

No.	Key Evaluation Criteria	2019 In-person	2020 Online
1	Total number of registered teams	829	549
2	Team dropout rate	4.2%	12.45%
3	% of Game teams with over 60% scores	22%	25.6%
4	% of Exhibition teams with over 3.0 judging scores	59%	93%
5	% of Game teams that solved unknown problems	37%	69.4%
6	Overall satisfaction rate by coaches	89.7%	95%
7	% of teams that tried 2nd Chance	33%	33%
8	% of students who indicate that Robofest experience helped them learn more about STEM	79.4%	96.7%
9	% of students who like STEM classes	85.5%	85.7%
10	% of students who consider a career involving STEM	91.1%	94.5%
11	% of coaches who indicate that Robofest experience helped students in learning core skills such as teamwork, leadership, creativity, communication & problem solving	100%	97.8%

As shown in Figure 1 and Table IV row No. 1, the total number of teams in the online year 2020 has dropped sharply. Team dropout rate, 12.45%, was also high as shown in row No. 2. However, as row numbers 3, 4, and 5 show, teams' robots performed better in scores than non-online years.

As shown in Table IV row 8, a majority of students (96.7%) indicated the Robofest robotics experience helped them learn more about Science, Technology, Engineering, or Math (STEM).

Percentage of coaches who indicated that Robofest experience helped students in learning core skills such as teamwork, leadership, creativity, communication & problem solving was slightly decreased from 100% to 97.8% in the online year as shown in Table IV, row 11. We think this is due to the lack of actual teamwork limited by online communication between team members. Also, there were an increased number of teams that had only one team member. They could not exercise teamwork skills.

We also asked students whether they liked the online format of the competitions and they are willing to participate again in the online competitions using a rate number between 1 and 5. Their likeness score was 3.8/5.0 and willingness score was 4.3/5.0. See Figures 15 and 16.

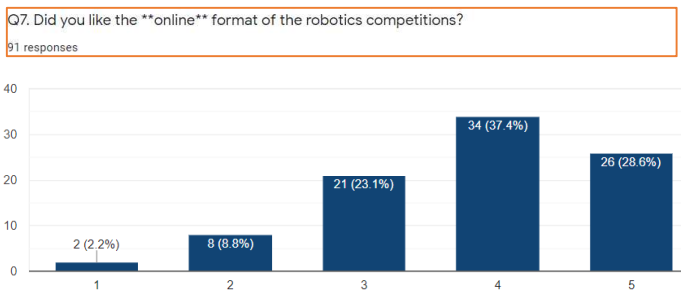

Fig. 15. Student survey result - Online format likeness

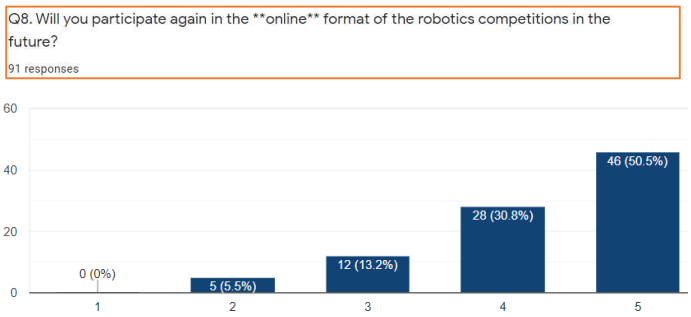

Fig. 16. Student survey result - Online format willingness to participate in again in the future

VI. DISCUSSION AND CONCLUSIONS

To overcome the unprecedented & unexpected global pandemic, we rapidly designed an innovative and novel live online synchronized robotics competition. Survey data show that Robofest Online World Championships (ROWC) provided a great opportunity for students to develop both hard STEM skills and soft skills such as online technical communication and remote teamwork skills utilizing internet tools. Even though a large number of teams dropped out, we believe the ROWC population was quite similar to that of previous years, since only hard-working and motivated teams were advancing to the world championships every year anyway. Our two research questions defined in the section I are discussed in the following subsections *A* and *B*. Subsection *C* will discuss additional observations and future work.

A. Research question: Will coaches, teachers, and students be satisfied with the online format?

Regarding the first research question, our data supported that they all were satisfied with the online competition format. Coach & judge anonymous survey results after the ROWC in October 2020 showed that the satisfaction rate was better than the in-person competition surveys of previous years. Dissatisfaction rate was zero for the first time in 21-year Robofest history. See Figure 17.

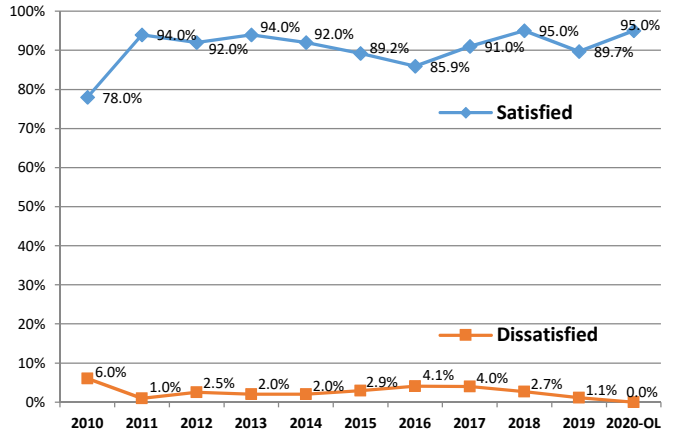

Fig. 17. Pre and post survey results for "Q5. Are you interested in a career involving STEM and/or coding?" from 2018 to 2020.

Students also showed satisfaction as shown in Figure 15 and 16. All the 2020 ROWC Coach Survey Comments done

anonymously can be found online at [17]. Some comments from the survey include:

- *We have done the live competitions for Robofest for 4 years. The UMC online challenge provided my kids an ability to stay connected to the familiar and challenged them in the many things that robotics stimulates. The experiences' working with robots provides my kids is priceless. Later, in the same day we completed the UMC, my youngest son started looking up videos to prepare him for BottleSumo and in the process created something he wanted to register for the exhibition. I think it shows that whether virtual or live, interest can be peaked and learning can be had and a joy for robotics can be created and continued. Thanks for your hard work this year in continuing to provide an opportunity for robotics competitions.*
- *Prefer the in-person event. However, so thrilled we were able to participate on-line since the in-person event could not happen. The world coming together around such a growth-oriented event is fantastic for students and adults alike. So thankful to be able to provide this opportunity to our students. On-line event is more cost effective.*
- *It was well organized. The students were able to complete the challenge they were given back in November and people from all over the world were still able to participate. It is definitely not the same as in person, but it allowed for students to still focus on robotics.*
- *The event was well organized and inspirational despite the difficulty of the online format because of the Pandemic. I would definitely stay involved if there was more local interest among students in the area. Unfortunately, very few students seem willing to take on the commitment to learn the programming required to compete in this small rural part of Nova Scotia. We are too far from the Acadia program to take advantage of the initiatives they create to stimulate interest and expertise.*
- *Kudos to Robofest team for making this happen regardless of the situation we are all in. Very well designed and distributed ONLINE tournament very well received.*
- *Absolutely love the program. Very affordable. Thank you for working so hard to make the online competition work and giving the students an opportunity to finish the 2020 season and not just end the season due to the pandemic*
- *Excellent online format given the circumstances. Congratulations to the entire Robofest staff. I believe the students learned more and gained confidence by being required to work more independently.*

B. *Effective in motivating students to learn STEM subjects and attracting into STEM careers?*

Regarding the second research question, our data showed that online competition format was effective for students in learning STEM subjects and getting students interested in STEM careers.

It is worthwhile noting that 96.7% of students surveyed after the ROWC exposure indicated that Robofest experience helped them learn more about STEM versus 79.4% of students surveyed after the 2019 in-person competitions, as shown in Table IV, row 8. It was a huge positive jump, 96.7% - 79.4% = 17.3%. Actual robot performance scores improved too as shown in rows 3, 4, 5 in Table IV. Both STEM subject likeness and STEM career interest were also increased as shown in Figures 13 and 14. 95% of students surveyed after the ROWC exposure said that they would now consider a career involving STEM versus 91% of students surveyed after the 2019 in-person competitions.

C. *Other observations and future work*

Even after the pandemic is over, we may continue synchronized online competitions in order to widen the opportunity for students. One of the advantages of online competition is the team-cost which is much cheaper than in-person competitions because of the travel and associated costs.

The Internet around the world was quite robust. A short outage occurred due to a power failure in a country. There were a few very minor issues with Zoom outages which did not impact any competition time.

We used to have a few human errors in in-person competitions when deciding winners, mainly due to the time limitations and time pressure to meet planned schedules. However, online competitions with a dedicated award ceremony day gave enough time to verify all the scores and double-check recorded videos, which resulted in no error in deciding winners.

Event start time was too early or too late for some regions around the world. We may think of regional competitions before the world final. Then we can optimize the start time considering only the countries advanced.

It took too much time to check if every location around the world was ready to run robots for synchronized Game style competitions. Finding ways to shorten that procedure is needed.

Future work will focus more on the metrics that can be extracted from the competition results. Pairwise t-tests and inclusion of control groups are also planned.

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REFERENCES

[1] Y. Zhang, R. Luo, Y. Zhu, and Y. Yin, "Educational Robots Improve K-12 Students' Computational Thinking and STEM Attitudes: Systematic Review," Journal of Educational Computing Research. February 2021. doi:10.1177/0735633121994070

[2] Chookaew, S., Howimanporn, S., & Hutamarn, S. (2021). Investigating Students' Computational Thinking through STEM Robot-based Learning Activities.

[3] C. Chung, Cartwright Christopher, and Matthew Cole. "Assessing the impact of an autonomous robotics competition for STEM education," Journal of STEM Education: Innovations and Research 15.2 (2014).

[4] ChanJin Chung, Christopher Cartwright, and Joe DeRose, "Robotics Festival and Competitions Designed for STEM+C Education," Robotics in STEM Education: Redesigning the Learning Experience, editor Myint Swe Khine, Springer, pp.131-170, 2017

[5] Chan-Jin Chung, "Robofest–A Playful Learning Environment Through Autonomous Robotics," *Pädi Boletín Científico de Ciencias Básicas e Ingenierías del ICBI* 7. Especial (2019): 1-3.

[6] https://en.wikipedia.org/wiki/Robofest (accessed on April 4, 2021)

[7] https://www.robofest.net (accessed on April 4, 2021)

[8] CJ Chung, "Integrated STEAM education through global robotics art festival (GRAF)." 2014 IEEE Integrated STEM Education Conference. IEEE, 2014.

[9] Michael Anft, "Deciphering a New Generation of Learners: High-school and college students' expectations of their educational experience during and after Covid-19." The Chronicle of Higher Education, 2021

[10] K.J. Gucwa, H.H. Cheng, "RoboSim: a simulation environment for programming virtual robots." *Engineering with Computers* 34**,** 475–485 (2018). https://doi.org/10.1007/s00366-017-0553-7

[11] Kevin J. Gucwa and Harry H. Cheng. 2017. Making Robot Challenges with Virtual Robots. In Proceedings of the 2017 ACM SIGCSE Technical Symposium on Computer Science Education (SIGCSE '17). Association for Computing Machinery, New York, NY, USA, 273–277. DOI:https://doi.org/10.1145/3017680.3017700

[12] Bradley Barker, Gwen Nugent, Neal Grandgenett, Viacheslav Adamchuk, Synchronous Educational Robotics Competitions in the Virtual World, EdMedia+ Innovate Learning, 2009, pp 3237-3242.

[13] https://www.robofest.net/index.php/prior-robofests/prior-year-world-championships (accessed on May 6, 2021)

[14] https://robofest.net/2018/robofest18report.pdf (accessed on May 6, 2021)

[15] https://www.robofest.net/2019/robofest19report.pdf (accessed on May 6, 2021)

[16] https://www.robofest.net/2020/robofest20report.pdf (accessed on May 6, 2021)

[17] https://www.robofest.net/2020/CoachSurvey.pdf (accessed on May 6, 2021)