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Online Robotics Project-based Learning Approach in a First-year Engineering Program

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Abstract

A first-year mandatory engineering project-based course aimed at developing an engineering mindset was taught through students engaging in active learning strategies built on the design-thinking framework by Ulrich and Eppinger. Course outcomes were achieved via students' participation in the fabrication of an autonomous robotic vehicle facilitated through practical hands-on activities, group discussions, and laboratory modules. Due to the COVID-19 pandemic, this formerly in-person course adopted a synchronous teaching model and used online instructional tools for lectures, group activities, and project support. The robotic project helped introduce students to engineering principles by employing multi-developmental phases for creating a robot. The teaching approach also provided students an engineering design experience while working in interdisciplinary teams with members serving unique engineering roles such as design, hardware, software, project, or testing lead. Students were required to design and fabricate a relevant prototype for stakeholders and, while doing so, learn and acquire essential competencies and skillsets relevant to engineering professions. Course methodology involved weekly assignments and the acquisition of project kits by individual students. The engineering mindset was assessed through content knowledge of inclusive modules in electronics, programming, 3D printing, innovation, and data analysis assignments.

Learning outcomes include using software, hardware-based technologies, and research-based inquiries to design, fabricate, test, and improve an autonomous robot. Measurement of these outcomes was accomplished through course assessments, student evaluations, and the final project showcase results. This remote course structure fostered an engineering mindset, technical know-how, innovation and promoted essential competencies like teamwork, leadership, and critical thinking. Despite the pandemic-transformed pedagogy, students acquired relevant toolsets for manufacturing, synthesis, analysis, and technology that support engineering solutions.

Introduction

Robotics has tremendous use in education and has helped improve daily life operations. Further advancements in miniaturization, automation, lightweight, and artificial intelligence technologies are at the forefront of current research for long-term usability [1-2]. Manufacturing robots as a pedagogical practice promotes student learning in different entities of the engineering field. Specifically, it involves knowledge of programming, electronics, design, and fabrication; thus, critical thinking and problem-solving stimulation are inevitable. Moreover, robotic competitions help train and motivate young students in STEM education as the engagement provides stimuli to solve tangible societal problems [3-6]. The practice of competitions and prizes in an undergraduate course effectively stimulates ingenuity and innovation to ascertain defined educational outcomes.

Prior to the COVID-19 pandemic, limited studies explored the impact of remotely teaching robotics on pedagogy for replacing or supplementing theoretical courses and traditional hands-on laboratories. Assessment of remote teaching on student performance revealed possible integration of online labs as effective learning environments. In a pilot study, students in traditional face-to-face training scored better in low-level technical dexterities like operations of buttons, while online students exhibited better concentration and motivation levels [7]. However, the differences were not statistically significant as such observations could not be attributed to the different teaching modalities. Nevertheless, large-scale studies are needed for standardizing teaching and learning practices. A comprehensive understanding of the differences between different teaching modalities in robotics has yet to be developed. Challenges faced included network integration, student engagement, teamwork, accessibility, technology, equipment, and robust communication platforms [8-10].

With the pandemic-transformed pedagogy, institutions had to switch to an emergency remote teaching modality. Instructors could not adequately support hands-on technology competency. At the same time, student motivation and engagement depreciated due to limited access to in-person interactions and resources – all of which instigated concerns about teaching and learning effectiveness in an online environment and its long-term sustainability [10]. Thus, remote instructional platforms had to be rapidly modified and deployed for theoretical-based courses and practical experimentation courses such as Robotics Lab.

Teaching robotics remotely poses a set of challenges, especially during a pandemic. Robotics manufacturing is a practical and interdisciplinary technology involving electronics, computing, and mechanical devices. Hence, strategic planning, organization, creation of didactic materials, and reliable synchronous communication platforms between all stakeholders are necessary to engage students and facilitate learning. Infrastructural tools and systems such as uninterrupted internet access, remote access, a virtual reality environment, and suitable electronic gadgets help navigate the process during the COVID-19 pandemic [11-14].

Recently, the benefits of teaching robotics courses online began to materialize, providing a promising path to standardizing best practices [15]. Grade-performance analysis showed improved learning outcomes compared to previous years of face-to-face instructional mode owing to changes in course structure and provision of extensive resource materials. Survey results from student feedback revealed indicators for high approval rates for the remote teaching modality.

The work presented herein reports a robotic design project framework taught remotely in a first-year engineering lab course and addresses challenges encountered during the pandemic. This paper does not cover the main tools, resources, and methodological frameworks devised for remote robotics teaching as reported elsewhere [11, 14]. Instead, this work provides a guideline that can serve as a model strategy and a valuable toolset for teaching any design-based project course online.

Methodology

Course structure and implementation

The Foundations of Engineering lab, EGN 3000L at the University of South Florida, is a three-credit course focused on the design process developed by Ulrich and Eppinger [16-17]. Incoming and transfer engineering students must take the course in their first year at the college of engineering. Enrollment exceeds 500 students per semester. In an attempt to reduce faculty to student ratio, the course is taught in multiple sections, with up to 90 students per section. Each section is staffed with a faculty member and up to three TAs. A program director is responsible for coordinating course materials, learning outcomes, disseminating assignment rubrics, and synchronized activities across all sections.

Pre-COVID, the course was a service-learning course with multiple design projects taught in a face-to-face classroom setting [18-19]. Modification of course materials and approach occurred during COVID with the core parameters remaining unchanged, especially the team-based projects, instructors, and TA distributions. Course content, projects, and assignments were streamlined to fit a remote instructional method and still meet the course outcome of students' ability to develop an engineering mindset and gain familiarity with design principles.

Course methodology utilized a thematic learning approach by using a robotic design project to educate first-year students on the fundamentals of engineering. Educational materials covered essential topics for conceptual design and fabrication of a robotic car. The introduction of materials occurred through synchronous lectures followed by practical online activities. Topics covered include Design Thinking, Computer-Aided Design (CAD), Fabrication method, Programming, Concept sheet generation, Instrumentation, Design Optimization, and some soft skills activities presented in Table 1. The learning outcomes for this course include software (e.g., CAD and Arduino IDE) and hardware training (e.g., circuits, breadboards, sensors, 3D printers) and research-based strategies (e.g., Design Heuristics, Engineering Design Process) to design, fabricate, test, and optimize an autonomous robot.

Participants

A total of 615 students completed the questionnaire and reported their geographical locations. Students took the course remotely from 30 countries across North America, Asia, Africa, and South America. Approximately 86% of students resided in the United States, followed by 2% in India, 1% in Bangladesh, Vietnam, Kuwait, China, Kuwait, Brazil, Uzbekistan, China, and Saudi Arabia. At the same time, less than 1% of the enrolled students were located in other counties. Overall, 85% of the 615 students resided in 65 different cities across the state of Florida.

Remote team collaboration and learning environment

Students were required to create novel autonomous robotic cars in teams of up to five members and each assuming individual lead roles. Execution of project assignment occurred via members completing their respective tasks as the Project Engineering lead, Test Engineering Lead, Software Engineer Lead, Design Engineering Lead, and Product Development (hardware) Lead. Tasks for each lead are often graded individually, and their specific duties are tabulated in Table 2. Students self-select into these roles with the possibility of switching up until the first group assignment.

Given the nature of this hands-on laboratory course, project teams were required to meet weekly online through Microsoft (MS) Teams to work on in-class activities and assignments. MS Teams channels were created for each group, and one Project Channel was established for each section to gain support during the fabrication phase of the robots. Groups with access to campus had the opportunity to print parts for their robots using the 3D printers available at the University's Design for Experience lab (Df*X*), a maker space designated for engineering students to tinker and use various engineering tools. At the end of the semester, groups presented their finished prototypes in an online showcase competition. All instructors teaching the course formed the judging panel to evaluate section finalists for the top three best robotic car prototypes.

Manufacturing Prototypes with Robotics Project kits

At the beginning of the course, students were given the project work order detailing the requirements for building an autonomous robot suitable for K-8 STEM education. Each group's prototype must have a manufactured enclosure built with either 3D printed parts, cardboard boxes, wood, repurposed materials, or any non-commercial pre-made robotics parts.

All students in the course were required to purchase the project kit listed in Table 3 from Amazon. The Elegoo Uno Project Super Starter Kit contains the essential components bulletized and some other valuable parts not listed. Students without access to Amazon may use the materials list to purchase items from different local vendors in their countries.

Student Reflection Surveys

Course benchmarks focused on responses from student evaluation surveys and performance on the final project showcase. Three sets of surveys were conducted to assess students' perceptions of the course. First, pre-course questions not listed in this paper gathered students' location and preferred team role assignment in the first week of classes. Students were then paired into a team of up to 5 students based on their survey entries. Additional surveys were conducted during the mid-and end of the semester. The survey questions shown in Table 4 was conducted mid-semester to analyze students' experience in the course with the intent to circumvent any pitfalls before the completion of the project. The survey evaluated student perceptions of the course, robotic project, team assessment, and self-reflection using an adapted form of the Wabisabi Learning 25 Self-Reflection questions.

Results and Discussion

In the COVID-19 pandemic, the EGN3000L course adopted a new structure to facilitate replicating in-person conditions and activities that support online learning. The objective was to have students gain a technical competency per module (Table 1) using a thematic approach of robotics technology. Course learning outcomes such as developing an engineering mindset, teamwork, and critical thinking skills were centered around learning to manufacture an autonomous robotic car. A project work order was shared detailing the engineering specifications and customer needs relevant for K-8 stakeholders. By the end of the course, students were required to present a functional prototype of their cars in an online showcase competition event. Qualitative evaluation of students' perception of the remote learning experience, the challenges faced, and the teaching practices for a robotics course are summarized below.

Table 1: Sample course schedule for a Fall semester

Wk	Lecture Topics	Lab Activities	Deliverables
1	**Course Overview** Project, Team Roles, Jigsaw assignment	Engineering Disciplines (Watch assigned videos)	Pre-Course survey
2	**Engineering Design-thinking** Customers' Needs vs Engr Specification Cosmetic Design vs Functional Design	Design Process Jigsaw	Design Process
3	**No Class** (Labor Day)	Tinker CAD tutorial (Bring a laptop/tablet)	Purchase project kit
4	**Manufacturing Technology** Intro to 3D Printing CRBP Orientation	Professional Dev. (PD)	CAD 1: Tutorial
5	**Engineering Tools** Arduino Programming Guide	Arduino Programming Lab (Bring yopur project kit)	CAD 2: Cosmetic Design PD 1: Learn it
6	**Ideation to Fabrication** Concept Ideation (Design Heuristics)	Design Heuristic Cards (Bring your CAD 2 work)	Programming worksheet Iteration & Improving
7	**Engineering Communications & Ethics** Memo Writing & Oral Communication Engineering Ethics & Intellectual Prop	Engineering Ethics: Case studies (Read cases before class)	Fabrication
8	**Design Review (DR) Presentations** (Business casual Attire)	Presentation Day 2	DR Presentation slides Memo 1 (Draft)
9	**Instrumentation Engineering** Electronics & Sensors	Circuit tutorial (Bring your project kit)	DR Document
10	**Design Optimization** Engineering Data Analysis	Design Optimization Survey	Circuit tutorial Memo 2 (Final)
11	**Entrepreneurship Mindset** Art of Innovation	Value Creation	Design Optimization Project Testing
12	**Engineering Technical Report** Writing an Executive Summary	**No Class** (Veterans Day)	Entrepreneurial Ad. PD 2: Show it
13	**Project Work Week** (Bring hardware to class)	Project work week	Executive Summary 1 Team Evaluation
14	**Project Showcase Competition** Showcase Part 1 (Business casual attire)	**No Class** (Thanksgiving break)	Showcase Portfolio
15	**Submit Executive Summary 2** Showcase Part 2	**No Class** (Reading Day)	Executive Summary 2 Post-course survey Project Reflection

Table 2: Description of Individual Roles in a Team

Engineering Lead Roles	Duties
Project	-Act as team lead and must understand all aspects of the project. Leverages how the engineering technology is integrated. Provides team status reports. -Generate, communicate, and maintains project schedule to ensure the team meets project deliverables. Lead the creation of the team presentation slides. Responsible for the bill of materials.
Test	-Inspects and reports on the functionality and safety of materials. Run tests on components to identify potential malfunctions and recommend potential solutions. -Responsible for implementing tests that ensure the quality of the final product. Verifies and validates the finished product for functionality, speed, and durability.
Software	-Write, debugs, and maintain programming codes to ensure the product meets standard operations. -Responsible for producing fabrication videos and photos
Product Development	-Manufactures the robots and assembles parts as a cohesive and functional final deliverable. -Responsible for the fabrication plan and manufacturing process. 3D printing training is necessary if using a 3D printer.
Design	-Creates and manages the CAD file for the final candidate design to ensure it meets guidelines for production and functionality. -Drafts the list of engineering specifications and selects parts and components needed for fabrication.

Table 3: Budget for essential project materials

Materials	Quantity	Estimated Cost
Digital Multimeter	1X	$10.00
L298N H-Bridge Motor Drive Controller	1-2X	$10.00
DC Motors with wheels	2-4X	$10.00
ELEGOO UNO Project Super Starter Kit: • 1X Ultrasonic Sensors • 1X 9V Battery and Button Connector Cable Clips • 1X Breadboard • Jumper Wires • Resistors • Buttons • LEDs • 1X Arduino Uno R3	1X	$30.00
	Total	**$60.00**

Table 4: List of course reflection questions asked students during mid-term

1.	List some things you find positive about this remote Lab course
2.	With respect to course structure, i.e., Lecture, Lab activities, Assignments, and the use of MS Teams. What are the things you wish we could do differently?
3.	With respect to Course and Lab content, i.e., Design Process, Programming, Fabrication, Design Heuristics, Instrumentation, Design Review Presentations etc. What are the things you wish we could do differently?
4.	What are your expectations or fears about the upcoming Project Showcase?
5.	Is your group supportive of each other? What are your thoughts about your team?

Table 5a: List of project reflection questions asked students at the end of the course

1.	What are your first thoughts about the overall project? Are they mostly positive or negative?
2.	If positive, what comes to mind specifically? Negative?
3.	How do you feel your project relates to engineering and real-world problems?
4.	What were some of your most helpful learning modules, and what made them so?
5.	What were some of your most challenging parts of the project, and what made them so?

Table 5b: List of team reflection questions asked students at the end of the course

1.	How well did you and your team communicate overall?
2.	When did your collaborative communications fall short of the group's expectations, if ever?
3.	What were some things your teammates did that helped you to learn or overcome obstacles?
4.	How did you help others during this process? How do you feel you may have hindered others, if at all?
5.	What could you do differently the next time you work with the same group or a different one?

Table 5c: List of self-reflection questions asked students at the end of the course

1.	What were some of the most exciting discoveries you made while working on this project? About yourself? About others?
2.	What did you learn where your greatest strengths? Your biggest areas for improvement?
3.	How did the remote teaching impact what you learned? Would you have learned differently if the course was in-person?
4.	What is the most important thing you learned about engineering?

Reflection Surveys suggests attained learning outcomes

Feedback from students' qualitative course evaluation during the mid-term (Table 4) was generally positive and constructive, with a response rate of 77%. More precisely, the statements from the survey are reported below to depict consensus among the class. Note that the statements are categorized with the table number followed by the question number.

- 4-Q1: *List some things you find positive about this Lab course*
  - "I think that the teamwork that occurs within the class is a great way for students to experience an environment similar to their career, especially since engineers are almost always working in small teams to accomplish a given task."

    - "For me, this project has been a major learning curve. While it is fun, it's challenging yet doesn't have a cookie-cutter solution like most classes do. The lab lectures are formatted for the forward motion of the project itself. Some students (especially online) might feel lazy. This gets them to be proactive and do their work on time."
    - "I like how it is all the interesting things I came to college to learn about, like electronics, robots, some coding, and I feel like the structure would work really well if it was in-person classes."
- 4-Q2: *With respect to course structure i.e. Lecture, Lab activities, Assignments, and the use of MS Teams. What are the things you wish we could do differently?*
    - "I would have liked to do the mechanical things in person because it can be hard to understand something and help other people with the arduino and wires and stuff through a computer."
    - "I find online school does not work well for me, so I think in person group work and lectures would be more beneficial"
    - "What I wish we could do differently is meet in person to work on our engineering project because it is super difficult doing it over teams calls."
- 4-Q3: *With respect to Course and Lab content i.e. Design Process, Programming, Fabrication, Design Heuristics, Instrumentation, Design Review Presentations etc. What are the things you wish we could do differently?*
    - "I think that maybe instead of doing only CAD tutorials for practice, if we had a simple prompt to come up with our own original cad design prior to designing the actual robot it might help to boost our creativity in preparation to making the candidate designs."
    - "I think that the lectures involving programming should be more in-depth and give us more examples to work through where we have to create our own variables and such."
    - "I can't think of much besides just transferring to entirely in person. I do not enjoy online work in the slightest."
- 4-Q4: What are your expectations or fears about the upcoming Project Showcase?
    - "My fears mostly stem from my social anxiety and tendency to get nervous when presenting. I also fear that unexpected issues may arise that affect the showcase such as exposure to COVID, the robot not functioning as expected during presentation, etc."
    - "I fear with being online that we will have trouble putting our final robot together without everyone being together."
    - "I do believe my group will pull through and get everything finished for the showcase, but I do have some fears that we won't be able to come together in person and complete the project together and have it be the best it could possibly be."
- 4-Q5: Is your group supportive of each other? What are your thoughts about your team?
    - "My group is very supportive, and we meet on Microsoft teams usually to finish our assignments. In addition, if anyone has a problem doing code or even assemble the wiring, we help him/her out until they figure it out. In my opinion, working with my group is very helpful."
    - "We are supportive of each other, the only bad thing I have to say is that some people are not very good at communicating, therefore some assignments do not get completed because of team members not responding."

- "It was difficult to work with each other sometimes because we live far apart from each other. One of my team members lives in another continent and the time/distance does cause issues with working together on the project and attending meeting. It's some what difficult to schedule a team meeting since we have other classes and one team member is in a far off time zone."

Students appreciated the project-based learning strategy and collaborative learning approaches utilized in the course. Still, many shared the need for face-to-face classes, especially for hands-on lab activities. Students requested more in-depth teaching of programming, which may or may not be limited due to teaching online. Anxiety and fears of presenting online and demonstrating their working robots were students' primary concerns. Working in a supportive team helped accomplish tasks effectively; however, communication and scheduling were the two main deterring factors mentioned mid-semester.

After the showcase competition, student responses from the survey in Tables 5a-c were completed with a response rate of 71%. Overall, approximately 91% of those students found the robot project positive and engaging, figure 1. Positive responses to 5a-Q2 included how students learned more about the field of engineering and how the project offered valuable technical knowledge and real-world practical experience. Students were intrigued about building a robot from an idea to a tangible end product. On the negative side, students unanimously echoed their lack of interest in online classes.

Here is a response from one student on the project reflection survey: "The positive attributes of this project are i) The engineering mindset given through following strict customer needs. ii) The process of identifying an issue and working relentlessly to solve it. iii) The aspects of communicating and organizing a team to reach a common goal. The negative experience was attributed to the online format of the course. However, it was unavoidable due to the pandemic. I feel as if we were in-person in a regular semester, this project could have been completed faster and more efficiently, as well as having more time for increased novelty features."

A significant part of the course is teamwork effectiveness. Regarding Table 5b questions, students attributed their team successes to the dedication and the willingness of members to help each other. However, the team's ability to build a functional robot depended on its members' collaborative, communicative nature. On 5b-Q5, many students said they would communicate better, work on time management and their schedule to be more accessible for team meetings.

The impact of remote instructional modality was captured in the self-reflection survey, Table 5c question #3. The responses were mixed, with the general thought that in-person learning would not be significantly better in terms of the actual knowledge gained but would provide attentiveness, accessibility, better logistics, and communication. Overall, students mentioned that in-person classes would allow a practical hands-on learning experience.

Thematic teaching of robotic projects remotely encountered challenges

A myriad of challenges occurred within a pandemic-transformed pedagogy. In this synchronous remote course, access to the Elegoo project kit from Amazon was restricted in some international countries, so a few students could not gain the hands-on experience needed to build the robot. The majority of the teaching challenges were with keeping students engaged and motivated during class. Also, it was difficult to obtain feedback from students while lecturing. At times, students had network connectivity issues and could not actively participate. Altogether, keeping students focused throughout the class period took strict adherence to the practice of evidence-based learning strategies.

Teamwork effectiveness was another significant challenge for students learning online with the limited social interaction. Students were placed in breakout rooms during lab activities to work on the exercises. Often, team members would not turn on their cameras nor participate in the small group discussion. Some groups reported an inability to reach their members outside of class. So, if respective students did not attend class, their group members had no means of contacting them.

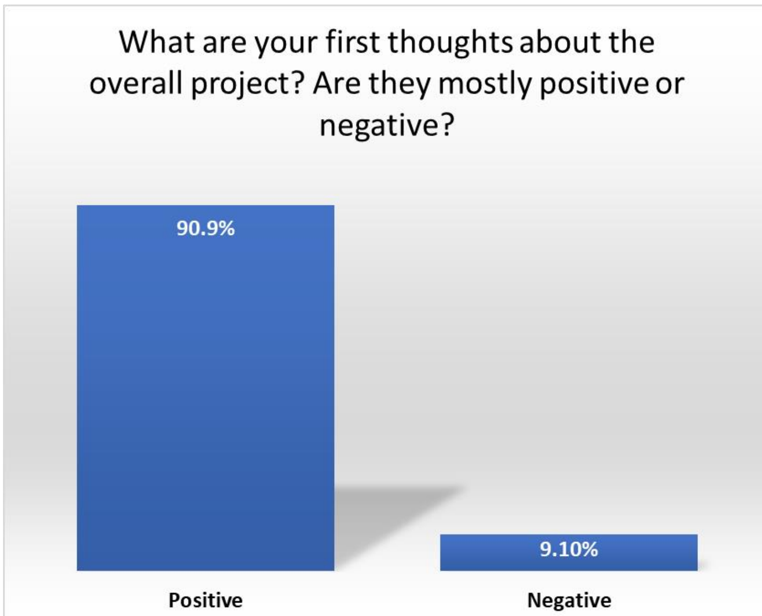

Figure 1: Most first-year engineering students' thoughts about the synchronous online robotics-based project course.

Lastly, student support and assistance with hands-on technical problems were logistically complex. For example, problems with circuitry are better managed when the breadboard, components, and wiring are physically accessible. Access to the 3D printers at the college of engineering DFX was limited. Students could not personally print their parts; the stereolithography files needed to be sent to a student technician for printing. As a result, there were multiple errors in some printed parts that could have been avoided if students had direct access to a physical 3D printer on campus.

Practices of teaching robotics remotely

There are several lessons learned from teaching this first-year engineering course remotely. The effects of a pandemic-transformed pedagogy were mitigated by considering the following:

- Periodic formative assessment should be performed to monitor students learning. This assessment should play a factor in team formation. There is an interplay between students' commitments and resulting team success [20].
- Use competitions to foster team-building between groups [4-6, 20]

- Assign individual tasks within group assignments for each team member throughout the fabrication phase of the project, similar to the divide and conquer collaboration model.
- Encourage team members to collectively create group charters and a contingency plan should a group member leaves.
- Frequently use pop questions or Kahoot-type games to encourage active participation during class.
- Create private channels for individual groups to use to communicate before, during, and after synchronous lectures.
- Host project support online channels/platforms equivalent to a help desk. This channel would serve to assist students with building a robot. Administrative support would be on standby throughout the day or as necessary.
- Provide continuous reminders and post announcements on all different course platforms.
- Arrange for project status meetings with individual teams to prevent future pitfalls.
- Establish peer-review evaluations to keep members professional and accountable.
- Provide recorded course materials. Videos are reported as one of the essential learning resources for Generation Z [15].

Conclusion and Future direction

One approach to remote teaching a robotics-based project is to use a learning management system for course materials and a communication platform to lecture and engage students. The robotic project-based learning approach introduces students to engineering by employing multi-developmental phases of creating a robot. Construction of robotics design from theoretical aspects of programming, fabrication, project design process, and electronics tinkering led to fruitful student learning outcomes. The teaching approach also provided engineering design experience while working in interdisciplinary teams.

Future work includes a thorough quantitative evaluation of the pedagogical impact of remote versus face-to-face learning and teaching. More assessment may be needed to validate the effectiveness of each modality. It would be interesting to address what instruments most impact teaching and learning effectiveness beyond the COVID-19 pandemic experience. Moving beyond the pandemic, remote technology coupled with online modules would be critical if not compulsory to educate the next generation in most STEM fields.

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