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Flood Rescue: A Gender-Inclusive Integrated STEM Curriculum Unit

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Abstract

As national reform documents and movements in the United States, such as *Next Generation Science Standards* (NGSS Lead States, 2013), push K-12 educators to begin to include engineering and integration of the STEM disciplines, there is a need to create curricula that meet a multitude of different standards. Additionally, there is a need to engage a more diverse population of students to pursue STEM careers. The 6th grade curriculum presented here focuses on an example of a teacher-created integrated STEM curriculum that combines girl-friendly instructional strategies (Häussler et al., 1998; Newbill & Cennamo, 2008) with an integrated STEM framework (Moore et al., 2014). An engineering design challenge that asks students to create a prototype of a watercraft used by the National Guard to rescue people during floods engages students in learning various physics concepts (forces, buoyancy, volume, and maximum capacity). In this article, we describe the lessons of the unit with respect to the frameworks, as well as key areas that particularly impacted 6th grade girls and boys.

Keywords: STEM Education, Engineering Design, Physics, Gender Equity

Introduction

Making science interesting for all students can sometimes be a challenge, but imagine if your students were excited by the prospect of engaging in an activity that connected to STEM careers. Imagine if that activity resulted in one of your female students being emphatic that she "could be an engineer and build boats and houses," because you had explained what engineers do with science and mathematics. One 6th grade girl felt this way after experiencing an integrated STEM curricular unit that aligned with what the literature calls girl-friendly science practices. During this unit, she and her classmates learned the physical science concepts of force and volume while designing a watercraft prototype for the National Guard to use during floods. Experiences like this one are necessary in today's educational climate to engage all students in active science learning and to make them aware of the opportunities that exist in STEM careers.

Reform documents, such as *Next Generation Science Standards* (NGSS Lead States, 2013), push science teachers to integrate engineering. This creates a need for curricula to address standards across STEM disciplines to engage a more diverse population of students to pursue STEM careers. Since K-12 experiences influence career choices, it is important to examine how curricula and instructional strategies play a role in developing students' perceptions of STEM fields. These curricula need to be supportive of a diverse audience in preparation for the new workforce; attention needs to be paid to those traditionally underrepresented. Women, for instance, are notably underrepresented in the fields of physics, engineering, and computer science (Scantlebury, 2014). Gender-inclusive education can have positive influences on girls' interest and achievement in science disciplines (Häussler et al., 1998; Newbill & Cennamo, 2008), and integrating engineering into science may help to gain and maintain self-concept and interest for young girls. There is a clear need to develop and understand how curricula that combine physics and engineering impact students' perceptions of these fields.

The curriculum presented here used a combination of frameworks to create an integrated STEM unit that appeals to both girls and boys through the inclusion of girl-friendly science instructional strategies. While a bit of a misnomer, these girl-friendly strategies positively influence *all* students' perceptions of science, but have a significantly larger impact on girls than boys (Häussler et al., 1998; Newbill & Cennamo, 2008). In this article, we present the key instructional strategies used in this unit that engaged students in learning, specifically focusing on the intersection of integrated STEM instruction (Moore et al., 2014) and girl-friendly science instruction (Häussler et al., 1998; Newbill & Cennamo, 2008). The goal of this work is to provide an example of an integrated STEM curriculum unit that has the potential to increase girls' interest in STEM and STEM careers.

The Curriculum Unit

This integrated STEM curriculum unit was created by three of the authors, Dr. Dare, Mr. Rafferty, and Ms. Scheidel as part of a large NSF-project that used the STEM integration framework of Moore et al. (2014). A total of 300 sixth grade students participated in the initial implementation of this unit in a school with the following demographics: 67% Caucasian, 13% African American, 12.7% Asian American, 6% Latino American, and 0.3% Native American.

A total 300 students in 9 sections taught by Mr. Rafferty and Ms. Scheidel participated in the implementation of this curriculum in Fall 2014. A subset of these students additionally participated in focus groups with Dr. Dare as part of a larger study (Dare, 2015). As part of this larger study, 28 students participated in four single-sex focus groups (16 girls, 12 boys) over the course of the year. These four groups represented an all-female group and all-male group from Mr. Rafferty's classes and an all-female group and all-male group from Ms. Scheidel's classes. One round of the focus group interviews took place shortly after the completion of implementation to gather students' thoughts and opinions about their experiences during this unit. The interview protocol used was designed specifically to capture students' experiences surrounding the integrated STEM unit. Transcripts of these interviews were coded to understand the general influence of instructional strategies on student perceptions of STEM, and these codes were used to determine similarities and differences of students' perceptions by gender using a constant comparative method for each case (girls and boys) to generate an understanding of with-in case groups (Corbin & Strauss, 2008; Miles & Huberman, 1994).

The three-week long unit included all of the aspects of Moore et al. (2014) integrated STEM framework and additionally aligned with girl-friendly science strategies (Table 1). An engineering design challenge required students to create a watercraft prototype that could save people during a flood event (Figure 1). Students needed to understand the concept of maximum capacity to "market" their design to a client - the National Guard. This required students to develop an understanding of buoyant forces and volume to calculate maximum capacity. Students worked in teams of four to learn about these concepts through various student-centered experiences. Though student teams designed their own watercraft, each class worked together through competition with other class sections. What follows is a description of each lesson, what STEM integration tenet(s) is/are addressed, and how it aligns to girl-friendly strategies to ignite STEM interest for all students. Student quotes from focus groups are included to share their perspective. The quotes presented here are exemplars that show common themes present in the student focus group interviews.

Table 1 Comparison Between Integrated STEM and Girl-Friendly Strategies in Flood Rescue

STEM Integration Tenet (Moore et al., 2014)	Brief Description	Why is it Girl-Friendly? (Häussler et al., 1998; Newbill & Cennamo, 2008)
Motivating and Engaging Context	Help the National Guard prepare for floods	1. Provide opportunities to be amazed 2. Link content to prior experiences 4. Encourage discussion and reflections of the social importance of science 5. Allow physics to appear in application-oriented contexts 6. Relate physics to the human body
Mathematics and/or Science Content	Volume, forces, buoyancy, maximum capacity	5. Allow physics to appear in application-oriented contexts 7. Experience physics quantitatively
Student-Centered Pedagogies	Hands-on laboratory experiences, class discussion	1. Provide opportunities to be amazed 2. Link content to prior experiences 3. Provide first-hand experiences 4. Encourage discussion and reflection of the social importance of science 8. Include cooperative and collaborative learning experiences
Engineering Design Challenge	Design a watercraft prototype to use in a flood	4. Encourage discussion and reflection of the social importance of science 5. Allow physics to appear in application-oriented contexts 8. Include cooperative and collaborative learning experiences
Learning from Failure	Initial testing of materials	No clear alignment
Teamwork and Communication	Working in groups, work as a class towards a common goal	4. Encourage discussion and reflection of the social importance of science 8. Include cooperative and collaborative learning experiences

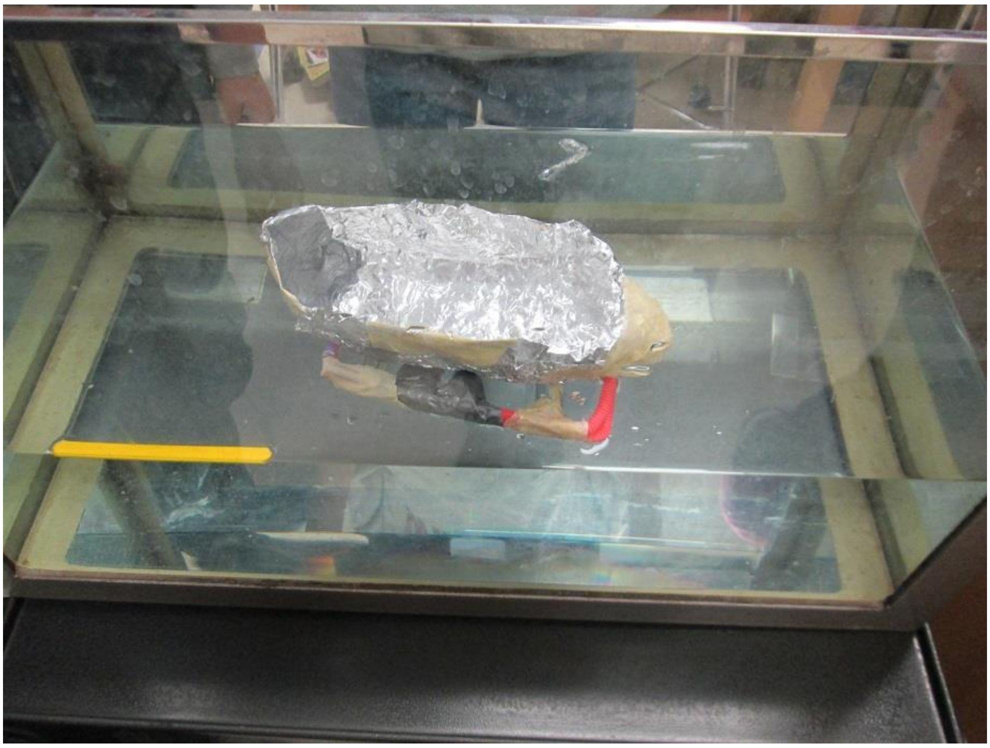

Figure 1. Example of finished student project.

Lesson 1: The Motivating and Engaging Context

Students were introduced to the engineering design challenge through a video message from their client - a member of the National Guard. In this video, he told students that they were to plan, design, test, and build a watercraft prototype to help rescue people in a flood. This motivating and engaging context was something students could connect to as the region had recently experienced major flooding. During this lesson, students worked in groups to analyze the client letter to identify what science and mathematics concepts they needed to learn to successfully complete the challenge.

While the idea of *boats* is frequently viewed as masculine, the context of saving people is something that appeals to a broader audience of students. This was especially important to girls, who connected to the real-world problem and saw the value in learning the science content saying, "I felt like we could do something." This lesson was viewed as different by students as it required them to see a relationship between physics, engineering, and society, compared to science-only lessons that provided students solely with content.

Lessons 2, 3, & 4: Inclusion of Science and/or Mathematics Content and Student-Centered Pedagogies

Lesson 2. Students were reminded of the engineering design challenge and identified the need to refresh and build on their knowledge of volume that they had learned in 5^{th} grade. The focus was to understand the relationship between cm^3 and mL through the use of centimeter cubes and graduated cylinders. Students calculated volume in multiple ways, such as filling a container with these cubes, using the formula for volume of rectangular prisms, and measuring volume of irregular objects through displacement. Making connections to real-world experiences (e.g., adding ice to a glass of water) helped students grasp the practical implications of volume.

Lesson 3. Students reviewed displacement and connected it to the concept of buoyancy through a large demonstration to show Archimedes' principle using a triple beam balance. On one side of the balance we placed a cubical container that we gradually filled with water; on the other side, we added mass to balance the scale. The goal of this lesson was for students to understand that (for water) not only does 1 cm^3 = 1 mL, but 1 cm^3 = 1 mL = 1 g. This was explicitly related to the watercraft challenge by discussing how to calculate maximum capacity. This lesson provided students with an introduction of what they needed to know for their design challenge in order to make sense of maximum capacity.

Lesson 4. Students reviewed measuring volume through displacement and were introduced to forces and force diagrams. This was done by explicitly relating to real-world experiences and to the design challenge. For instance, one boy shared,

> I liked how [my teacher] explained [buoyancy] - like, we would think of it like jumping into a pool. As we go down, the water goes up. It's cool to think about because I swim a lot. So it was cool to think about it that way. And then I realized – and then I really thought about it - and then I was like, "Oh, I already knew all of this!"

For the science content-heavy lesson of the unit, students took notes, but also engaged in discussions, demonstrations, and first-hand experiences with spring scales and buckets. Once a foundational knowledge of forces was built, students completed a station activity where they experienced buoyant force on objects immersed in water; students submerged objects hanging on a spring scale in water. They also tested how different empty soda bottles (e.g., 250mL, 1L, and 2L) reacted to being pushed into water to see and feel the buoyant force. They learned that the greater the volume of the object below the water-line, the greater the upward force on the object. By connecting this back to maximum capacity, students were able to see the relationship between mass, volume, and buoyant forces.

Lesson significance. Lessons 2, 3, and 4 focused on the central physical science concepts of volume and forces so that students could thoughtfully plan and build their watercrafts, building off of student prior knowledge of volume. The student-centered pedagogies used during the unit were appreciated by our students, who were fans of hands-on activities that allowed them to interact with materials in meaningful ways. This impacted both girls and boys, who felt that having real, relatable experiences with science was how they learned best. Discussing these experiences in small and large group discussions were an important part of students' learning since the sharing of their ideas helped others learn.

Lesson 5: Engineering Design Challenge, Learning from Failure, and Teamwork & Communication

In this final lesson students applied concepts of mass, volume, and buoyancy to design a watercraft that could hold the maximum capacity as predicted by calculations. Students were given a budget for available materials (aluminum foil, regular straws, bubble tea straws, craft sticks, film canisters, hot glue, and duct tape) in order to minimize the amount of waste in the classroom and guide students to critically plan their design (Figure 2). We also provided students with a "junk yard," where students could purchase discounted "recycled" material that would otherwise go to waste. Students used an engineering journal to document their progress and decisions (Figure 3).

Figure 2. Materials available to students for the engineering design challenge.

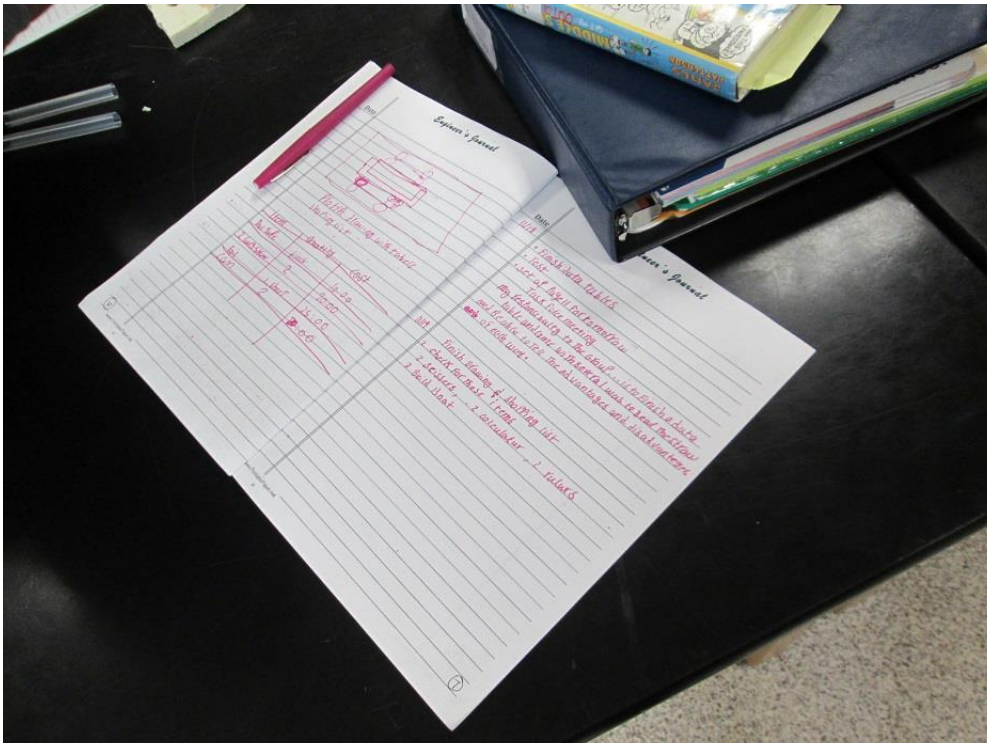

Figure 3. Engineering journal example.

Day 1: Plan for mini-tests. Students were introduced to the materials available for the engineering design challenge and discussed what they might need them for. Given a budget, students needed to plan thoughtfully. For example, a film canister might be useful as a way to increase the maximum capacity, but it is an expensive material. For this initial testing of materials, students were to take on roles to become experts in their team (Table 2). This division of labor honored each team member's responsibility and importance to the team due to the individual roles that we created. Each student was responsible for the success of their watercraft prototype, so that the team would draw on the knowledge of each "content expert" to make important final design decisions. We related these roles to the field of engineering as engineers with different expertise collaborate to finish a job.

Table 2 Description of Student Roles in Engineering Design Challenge

Role	Description of Role and Tips for Implementation
Lead Designer	Tests different types of watercraft shapes and designs. Having pre-made shapes are helpful so that students can spend more time testing. Students could also test to different weights of aluminum foil. The heavier brand could be set at a higher price so groups should have data on how much of an advantage the thicker foil would be.
Keep It Together Crew	Tests different ways to keep materials together such as hot glue, duct tape, and masking tape. Another task that this group can do is to test folded aluminum for leaks. For example, test whether the fold should be taped to let in less water. Leaking of the aluminum was the biggest problem with the final designs and caused the most failure.
Straw Sealer	Tests different ways to seal the straws and keep water from entering. Straws should be weighted down below the surface of the water.
Math Master	Works on calculating the volume of the different shaped objects that could be used, such as the film canisters and bubble straws. This individual can also keep track of material costs.

Day 2: Implement materials tests. Students worked in their groups and tested materials, recording data and observations in their engineering journals. The cooperative learning roles implemented in this lesson enabled us to help our students be comfortable with the idea of failure; we told them that this was a natural part of engineering. Students tested in their expert area with other experts in the same "field" (e.g., all of the Straw Sealers worked together) before coming back to their team. This combination of working in a team where it was ok to fail individually appeared to be especially important to female students, as one girl noted,

> I like how you get to talk with your group with ideas and then you get to actually test it instead of just thinking about it and deciding which one to do and then you just do it. I like how you get to test out different ideas before you choose one so that if you picked a bad one, then you get a chance to do a different one.

By allowing students to learn from individual failure, we encouraged them to discuss their experiences with their team members. Students felt that they had the wiggle room to mess up on their own, but still succeed because they were working with others.

Day 3: Reflect on initial testing. Students discussed their results from their materials testing, first by talking in their own team, then by sharing out the findings for each role. With input from other groups, students learned results from tests that they did not conduct personally. This allowed students to have a collective understanding of good design decisions, so that they could move forward with planning their watercraft design with their 4-person team.

Day 4-5: Plan, design, build, and test. Students worked in groups to plan, design, build, and test their watercrafts; this included sketching and labeling designs. Students worked in their small groups, but were reminded that they were really a large group, competing against other classes. This created a sense of responsibility to help other teams in their class and had been intentionally designed to encourage the sharing of ideas among all. For instance, one group had completed their prototype and was left with money in their budget and asked if they could give it to another group that needed more money for materials. Talk about teamwork and dedication! As students followed the design process, they calculated volume of the individual pieces so that they could determine the maximum capacity of their watercraft. All students worked on a "final report" page in their engineering journal (Figure 4), which needed to include details and labels on the design drawing as well as information about volume, mass, and maximum capacity.

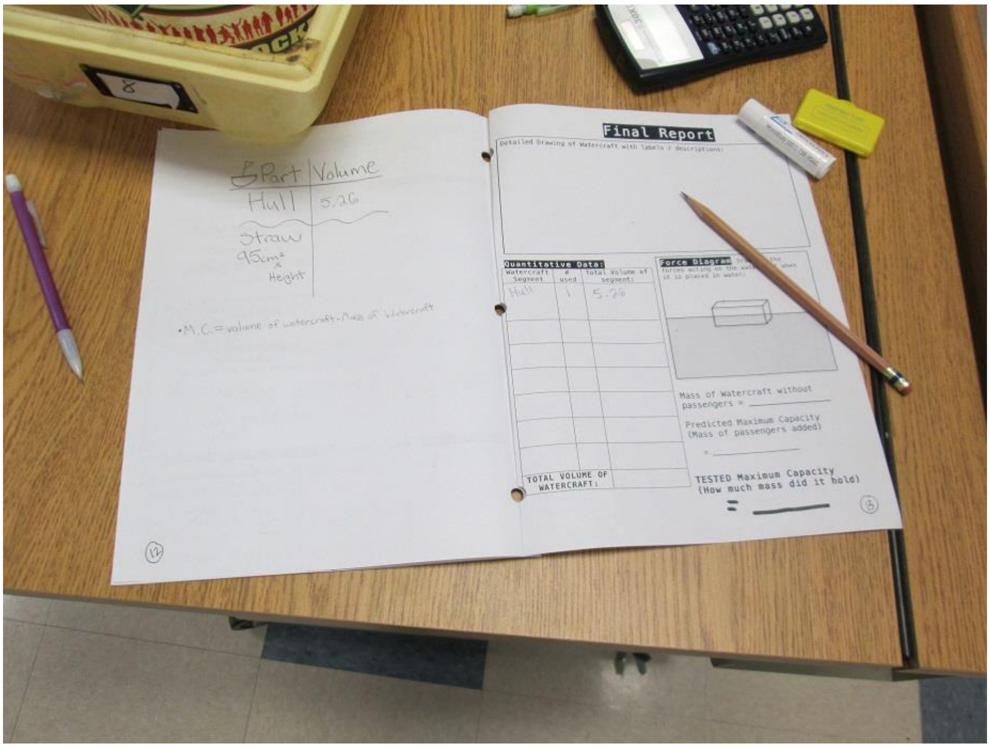

Figure 4. Final report of watercraft prototype.

Day 6: Final testing. Each group tested their watercraft in a large tank of water, adding mass to the watercraft to the predicted maximum capacity. To emphasize the real-world aspect of this design challenge, we used figurines in the shape of people and animals that the students could imagine their watercraft rescuing. Those that did not sink were counted as successful in meeting the challenge. At the end of class, students reflected on the success or failure of their watercraft in their engineering journal.

Day 7: Discussion, reflections, and wrap-up. Though there was not enough time for students to redesign their watercrafts, students wrote reports to their client. Students included and explanation of their design process, specifications of their design, available data on their design, and an explanation of why their design should be chosen. Students also included advice that they would consider to improve it. We reminded to use complete sentences and provide thoughtful comments about their design, using their observations and notes from their testing to provide claims, evidence, and reasoning in their letter.

Lesson significance. This engineering design challenge provided students with first-hand experiences, while the cooperative and collaborative learning created in these classrooms helped to illustrate the social nature of science. While students worked in teams in Lessons 1-4, the teamwork in Lesson 5 was imperative to their success, given the individual accountability of the different roles. Teams also competed across different sessions (i.e., if you teach three sections of 6th grade science, have each of these classes compete with one another), which allowed students to learn from others in their class, as opposed to putting external pressure on them to be the best.

Both girls and boys enjoyed working in teams, but approached teamwork slightly differently. Boys saw that working in a group was beneficial because they could "divide and conquer" the tasks. Girls saw an opportunity to gather ideas and opinions from peers without feeling judged because they were part of the same team. One girl noted, "I liked that we were competing with [different classes] so we could hear different people's…the whole [class's] ideas to improve our ideas." While boys also saw this positively, they were more focused on distributing the workload, "…since we had the teams –then we wouldn't have to worry about having to do everything ourselves. And then we would have different ideas to try." This unit provided students with opportunities to work both independently and talk with peers about their successes and failures, building a community among the class.

Conclusions

We learned several key aspects from students to keep in mind when brining engineering to the science classroom. Girls were much more attuned to the real-world connection of this unit as they had an opportunity to, "…actually build stuff. It wasn't just testing. We got to be in groups and interact with other people instead of sitting there taking notes." Boys were excited to *practice engineering* where, "We got to design. We got to be an engineer ourselves." It is clear that these first-hand STEM experiences were extremely powerful for students and having these experiences tied to a motivating and engaging context was beneficial in connecting them to their learning, especially for girls. By allowing students to see how physics is applied through an engineering design challenge, they were able to make connections between physics, everyday experiences, and engineering. It is clear that strategies like the ones described here have an impact on students' perceptions of STEM careers and provides hope in engaging a variety of learners through STEM integrated curricula. The curriculum described here provides one example that highlights important features to keep in mind when bringing integrated STEM education to the science classroom. It is apparent how educators might design girl-friendly integrated STEM curricula that generate positive perceptions of science and STEM for their students. These dimensions should not be overlooked when designing new curricula. Continued efforts in this area will hopefully ignite and maintain interest in STEM and STEM careers for all.

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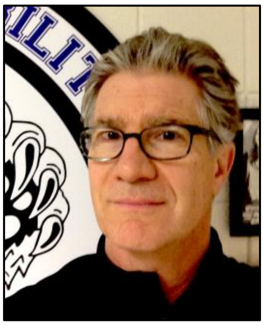

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