FUTURE U.

Space Ergonomics

Objectives

Students wil be able to:

- **Research** and **summarize** the importance of exercise in space.
- **Redesign** the International Space Station's fitness center while accounting for ergonomics and space constraints.
- **Analyze** the design of their peers through the lens of simulated motion capture technology testing.
- **Develop** suggestions for design optimizations from a human factors perspective.

Lesson Overview

As new employees on Boeing's Human Factors Team, students are tasked with their very first project: a complete redesign of the International Space Station's fitness center. Students will begin by exploring the concept of ergonomics and the importance of exercise in space before they move on to redesign a fitness center that meets the astronauts' needs in as small a space as possible. Students will then simulate motion capture testing as they evaluate each other's plans and provide concrete suggestions for improvement.

This lesson focuses on

Engineering Design Process

- Defining the Problem
- Designing Solutions
- Refine or Improve
- Communicating Results

21st Century Skills

- Communication
- Collaboration
- Critical thinking
- Creativity

Timing

Three 50–60 minute class periods

Materials

ALL DAYS

- Computer or device with the ability to project, one for the instructor

DAY 1

- Design Fail Images 1, 2, and 3: to project
- *Emily Howard: Human Factors Engineer* at Boeing video (until 2:40), to project

- *Innovating the Future Virtual Field Trip* video clip (19:28-21:08), to project
- International Space Station fitness center images (1 and 2), to project
- User Needs Evaluation handout, one per student
- Devices with internet access, at least one per every two students

DAY 2

- Fitness Center Redesign Packet (3 pages), one per every four students
- F18 Spar Installation video, to project
- Rulers or measuring tape, at least one per every four students
- Motion Capture Technology Image, to project (page 12)
- ISS Fitness Center: Motion Capture Technology Testing Packet (3 pages), one per every four students

DAY 3

- Painter's tape, one roll per every four students
- Rulers or measuring tape, at least one per every four students
- Device that can capture and save video, one per every four students

Have you ever wondered…?

Why is exercise important in space?

Astronauts can lose as much as 1% of their bone density each month that they are in space due to the change in gravity. Less gravity can also cause body fluids to shift upwards, which can cause swelling, high blood pressure, and organ problems. In addition to carefully considering nutrition and the need for extra medications, exercise plays a huge role in countering the effects of this gravitational shift. Consistent daily exercise can help prevent bone and muscle loss while also strengthening the cardiovascular system.[1]

What are ergonomics and human factors?

The terms “ergonomics” and “human factors” are used interchangeably. They involve the study of designing devices and environments so they can be easily used by humans. In other words: Human factors and ergonomics ensure that products, spaces, and systems fit the people who use them. In order to do this, this field takes people’s physical and cognitive capabilities into account before, during, and after the design process.

Make Connections

How does this connect to students?

The field of human factors and ergonomics affects students daily—and will continue to throughout their entire lives. Every tool, product, machine and system that we use has likely been analyzed from a human factors/ergonomics perspective to ensure that it is safe, comfortable, and effective for us to use. From airplane seats to school desks, ergonomics and human factors specialists have played a role in their development!

How does this connect to careers?

Ergonomics and Human Factors Specialists apply their knowledge of the human muscular and skeletal systems and their observations of how people move to ensure that people's interactions with products and their environment are safe, healthy, and efficient.

Human Factors Engineers design environments and objects with people's well-being and performance in mind. Some of the data and tools they use include anthropometrics (data of the dimensions of the human body) and motion capture technology testing (which tests designs on avatars before, during, after development).

Human Factors and Engineering Psychologists work to improve people's everyday lives by studying what people expect from products and technologies and how people interact with them in order to make products that are safer, more intuitive, and easier to use.[2]

How does this connect to our world?

Commercial spacecraft like the CST-100 Starliner hope to open a new market soon for tourism in low Earth orbit. Furthermore, research underway on the International Space Station (ISS) is enabling humans and technology to operate in space for months at a time.

There is therefore an ever-increasing chance that citizens of our world will get to experience space in their lifetime.

Human factors and ergonomics have already played a role in astronaut space travel and the International Space Station, which serves as a temporary space home to astronauts from around the world. As space travel extends beyond astronauts, an understanding of the impact of space travel on the human body and how to develop environments that ensure these travelers are safe and comfortable will be only grow in importance!

Sources

[1] "Space Travel: Here's What Happens to the Human Body." BBC News. bbc.com/news/world-42627341.

[2] A Career in Human Factors Psychology. American Psychological Association. https://www.apa.org/action/science/human-factors/education-training.

Blueprint for Discovery

DAY 1

- Divide students into groups of two or three. Then begin by projecting these design fail images (1, 2, and 3), one at a time. As you show each image, prompt groups to discuss:
    - Where did the design fall short?
    - What risks are associated with this design?
    - How could this design have been better implemented?
- Explain that one key factor that goes into design is called human factors and ergonomics. Play the *Emily Howard: Human Factors Engineer at Boeing* video (until 2:40) and ask students to listen especially closely to what human factors and ergonomics entails.
- When the clip is complete, invite students to think-pair-share: What is ergonomics and human factors? How is this field related to the design fails you examined?

  **Note:* In a think-pair-share, students think about the question independently, discuss their answers with a partner, and then share their thoughts with the larger class.
- Next, shift gears and instruct students to close their eyes for a moment. Tell them to imagine that they have jumped into the future and, like Emily, they now also work on Boeing's Human Factors team. However, unlike Emily, their specific team focuses on life in space! Go on to explain that their first project is an important one: Their team has been tasked with redesigning the fitness center at the International Space Station!
- Briefly explain that the International Space Station (ISS) is a large spacecraft that orbits Earth and is used as a science laboratory. Countries from around the world collaborated to build it beginning in 1998, and international crews live there today.
- Tell students that the Johnson Space Center in Houston, Texas has a full-size model of the ISS. To gain a better idea of what their first project will entail, the class is about to hear from a Mission Evaluation Room Engineer at Boeing who works to ensure that systems on the ISS support the health of the astronauts. Instruct students to listen and watch especially closely for what the ISS gym currently includes. Then play the *Innovating the Future Virtual Field Trip* video clip from 19:28 to 21:08
- Once the video clip is complete, ask a couple students to recap the equipment in the ISS fitness center. Then project these two ISS gym images (1 and 2), and explain that ISS would like the gym redesigned because the equipment is too bulky and takes up too much space! This not only makes it difficult to exercise but also makes it hard to move around the fitness center.
- Tell students that in order to redesign the ISS fitness center, it is crucial that they understand how and why astronauts exercise in space.
- Divide students into new Human Factors teams of four, and distribute one User Needs Evaluations handout to each student. Explain that for the rest of class, students will perform research to answer the provided research questions. They must begin with the suggested websites, and then they may move on to other sources if time allows. Tell students how much time they will have to complete their research, and encourage groups to split up the research questions if needed.

  *Note: If groups do split up their research, remind students when there are 10 minutes remaining so groups can share their research with each other.

DAY 2

1. Begin class by challenging students to perform a variation of one of the space exercises that they researched. For instance: Rather than running on a treadmill, students may run in place.
2. After the class has exercised for a couple minutes, ask students for a reminder of how long astronauts must exercise each day (Answer: at least two hours every day!) and why they must do this. (Answer: It's the most effective way to counteract the effects of weightlessness on the human body.)
3. Then announce that it's time to begin redesigning the fitness center at the International Space Station! Instruct students to get back into their Human Factors teams. Then distribute one Fitness Center Redesign Packet (3 pages) to each group. Instruct teams to work together to carefully read each step's instructions and complete the directions one step at a time. Tell the class that they will have about 30 minutes to complete this packet.
4. Regroup when time is up, and share that it is now time to review the proposed fitness centers from a human factors and ergonomics perspective.
5. Explain that one way each Human Factors team can assess whether designs are safe and comfortable is through motion capture technology testing, which is a type of technology that simulates real-life human motion within designs *before* they are actually built!
6. Project and play the F18 Spar Installation video and explain that this motion capture technology testing was used to assess the number of mechanics needed to lift a 70-pound spar (e.g. pole), as well as the movements that the mechanics could safely make as they lift this pole.

   As the video plays, point to the table on the bottom left of the screen and explain that the software is tracking the different ways that lifting the pole affects the users' spines.
7. Then project the Motion Capture Technology Image handout, and explain that this is an example of the results of motion capture technology testing. By using anthropometry (the study of the measurement and proportions of the human body) combined with the machine's design, the motion capture technology is able to analyze the effort that each person exerts. It then uses this analysis to calculate the effect of this activity on each part of the mechanic's body!
8. Tell students that the next step for the Human Factors teams and their fitness center redesign project is to simulate this motion capture testing on another group's plan! Exchange each team's Fitness Center Redesign Packet with another team's packet. Try to keep each exchange down to one (e.g. Teams A and B exchange, Teams C and D exchange, etc.) so it is easy for partner-team discussions to occur later.
9. Once each team has a new redesign to assess, also distribute one ISS Fitness Center: Motion Capture Technology Testing Packet to each team. Read through the first two steps together, and then challenge each team to get as far through the first two steps as they can in the time remaining in class!
10. At the end of the class session, instruct each team to save their two packets in a safe place or collect them and redistribute them at the beginning of the following class session!

DAY 3

Instructor Note: Before class begins, select a location where students will be able to put painter's tape on the floor/ground to outline the dimensions of their fitness center. An area like a blacktop or empty cafeteria may work best, but a combination of classroom and hall floor space will work as well!

1. As class begins, instruct students to regroup into their Human Factors teams and finish and/or review the first two steps on their Motion Capture Technology Testing Packet.
2. Then explain that for the majority of today's class period, each group will simulate motion capture technology testing so they can suggest improvements for the fitness center they are evaluating!
3. Briefly review Steps 3 through 6 in their packet, and explain where the testing will occur. After answering any questions, distribute a roll of painter's tape and a ruler/measuring tape to each group. Also be sure each group has a recording device.
4. If necessary, lead students to their testing area. Split the space evenly among the groups so teams have an understanding of how much of their fitness center they can test at one time. Then encourage them to get to work!
5. Rotate throughout the classroom and keep an eye on the clock as team perform their testing. Deduct ten minutes from the end of the class period, and give students a reminder when 15, 10 and five minutes remain.
6. For the last 10 minutes of class, instruct each group to pair up with the team whose plan they reviewed. Each group should explain the results of their motion capture testing as well as the modifications they suggested based on their analysis.
7. Finally, conclude by thanking the Human Factors teams for their hard work, innovative designs, and thorough review. Because of work like this, safe, comfortable, and useful products *and* environments can exist both on Earth and in Outer Space!

EXTEND

Students can use a free design software like SmartDraw or FloorPlanner to create a three-dimensional mock-up of their final plan that takes the recommendations provided by the motion capture technology testing into account.

National Standards

Next Generation Science Standards

Engineering Design

- MS-ETS1-1: Defining and Delineating Engineering Problems

  The more precisely a design task's criteria and constraints can be defined, the more likely it is that the designed solution will be successful. Specification of constraints includes consideration of scientific principles and other relevant knowledge that are likely to limit possible solutions.

- MS-ETS1-4 Developing Possible Solutions

  A solution needs to be tested, and then modified on the basis of the test results, in order to improve it.

Common Core State Standards: English Language Arts

Science & Technical Subjects

- RST.6-8.1 Cite specific textual evidence to support analysis of science and technical texts.

Speaking & Listening

- SL.1 Prepare for and participate effectively in a range of conversations and collaborations with diverse partners, building on others' ideas and expressing their own clearly and persuasively.

Common Core State Standards: Mathematics

Ratios and Proportional Relationships:

- 7.RP.A.2 Recognize and represent proportional relationships between quantities

Geometry:

- 7.G.A.1 Solve problems involving scale drawings of geometric figures, including computing actual lengths and areas from a scale drawing and reproducing a scale drawing at a different scale.

User Needs Evaluations handout

Suggested Websites:

1. asc-csa.gc.ca/eng/astronauts/living-in-space/physical-activity-in-space.asp
2. nasa.gov/audience/foreducators/stem-on-station/ditl_exercising
3. science.howstuffworks.com/exercise-in-space.htm
4. esa.int/kids/en/learn/Life_in_Space/Living_in_space/Exercise

Research Question: Why is each type of exercise below important in space?		
Bone Strengthening Exercises	Muscle Strengthening Exercises	Cardio (Heart and Lung Strengthening) Exercises

Research Question: How does each piece of fitness equipment aboard the International Space Station currently work and why is it important?

Tip: Use Websites 1 or 2 to watch a video about each piece of equipment!

Treadmill (e.g. Treadmill Vibration Isolation System or TVIS):

Mechanical Bike (e.g. Cycle Ergometer with Vibration Isolation System or CEVIS):

Weight-Lifting Device (e.g. Resistive Exercise Device or RED)

Fitness Center Redesign Packet (page 1 of 3)

STEP 1: REVIEW

1. Below are the exercise machines used at the International Space Station. Select a team member to simulate using each machine. As they do, measure how much space is needed to perform the exercise (including length, width, and height)! When you take the measurements, be sure to include extra space that may be needed for the machine.

   Record your measurements in the white boxes below:

	Length	Width	Height
Treadmill			
* New & Improved Treadmill: What will you change?			
Bike			
* New & Improved Bike: What will you change?			
Weight Lifting Device			
* New & Improved Weight Lifting Device: What will you change?			
*** New Addition: _____ Description:**			

STEP 2: BRAINSTORM

1. Could you change the workout machines so they take up less space but accomplish similar results? Be creative! Describe changes you could make to each machine in the *New & Improved* grey boxes above.
2. Simulate what exercise on these modified machines may look like, take measurements, and record the new measurements in the grey boxes above.
3. Brainstorm one new machine or exercise space that would beneficial and/or fun for the astronauts. Describe this in the *New Addition* box above.
4. Then simulate this new machine or new workout, measure how much space is needed, and record the dimensions above.

Fitness Center Redesign Packet (page 2 of 3)

STEP 3: REDESIGN

You're now ready to create a plan for the redesign of the ISS Fitness Center! Your redesigned gym must:

- ✓ Include your new and improved machines.
- ✓ Consider human factors and ergonomics and ensure the design is safe and comfortable.
- ✓ Take up as little space as possible.

To begin your redesign:

1. **Create a Scale**

   If your fitness center diagram is drawn to scale, all parts of your diagram will be smaller than the actual fitness center by the same amount. For instance, a scale might say that one inch on your diagram = 1 foot in real life.

   Take a look at the grid on page 3. This is where you will draw your gym design! Decide what one side of a grid square will equal in real life, and then record your scale on Page 3.

   Tip: Make sure you choose a scale that won't make your diagram too small or too big!

2. **Sketch your Design**

   Use your scale to draw the fitness center's new design in the grid on page 3. Think about the space needed for your equipment as well as the space needed between your equipment!

3. **Label your Diagram**

   Label each piece of equipment and its dimensions. Then draw an outline of the room so viewers can understand the size and shape of the entire fitness center.

STEP 4: RECAP

Based on your to-scale diagram, what is the size of the new ISS fitness center?

Length: _____ Width: _____ Height*: _____

*The room's height may not be included in your diagram, but think about the height that this room would need to be compact but also as ergonomic as possible!

Fitness Center Redesign Packet (page 3 of 3)

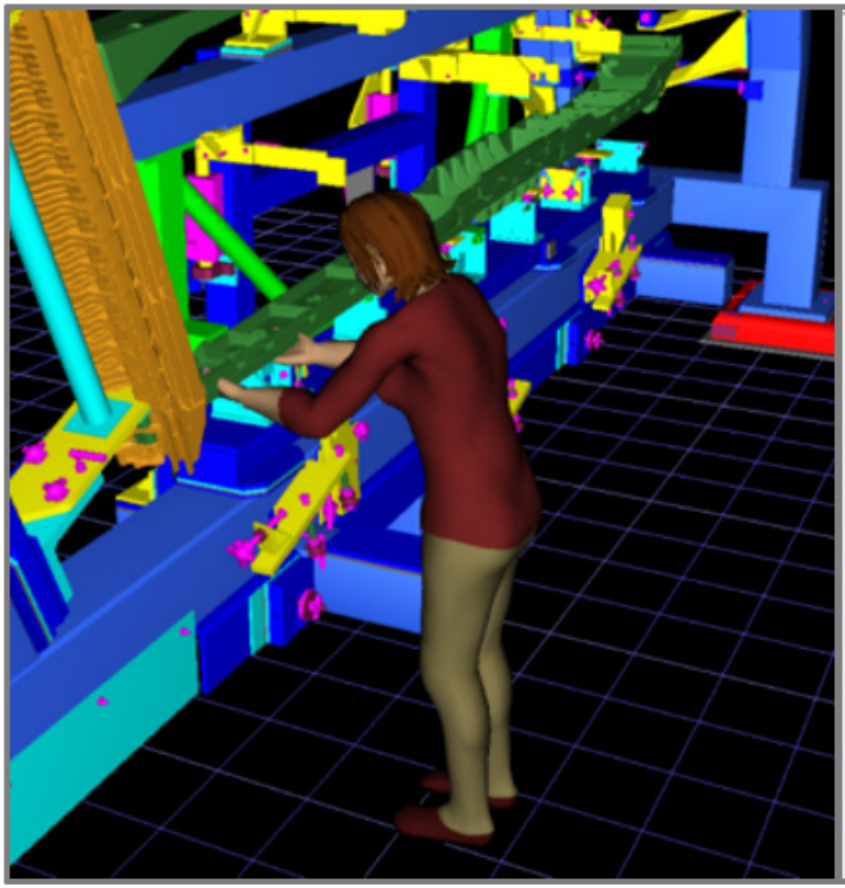
Scale: ——— = _____

International Space Station Redesign Proposal

XR Extended Reality Center of Excellence — Philadelphia Design Center

Spar Lift and Placement Assessment

(Spar weight: 70 lbs)



Ergonomic Analysis

Sort by: Joint — Angle convention: Jack

Joint/Axis	% Capable	Use	Moment (Nm)	Muscle Effect	Angle (deg)	Strength Mean (Nm)	Strength Std Dev (Nm)
R Wrist Flx	89	✓	-3.8	FLXN	0.0	6.4	2.0
L Wrist Flx	86	✓	-3.9	FLXN	0.0	5.9	1.9
R Wrist Dev	100	✓	-1.1	RAD	-0.0	6.9	2.2
L Wrist Dev	100	✓	-1.1	RAD	-0.0	6.4	2.1
R Wr SuPr	100	✓	0.2	--	93.2	--	--
L Wr SuPr	100	✓	0.2	--	93.2	--	--
R Elbow	90	✓	-20.6	FLXN	51.8	31.0	8.1
L Elbow	86	✓	-20.7	FLXN	51.8	28.8	7.6
R Sh AbAd	46	✓	-34.5	ABD	58.1	33.6	8.8
L Sh AbAd	35	✓	-34.4	ABD	58.1	31.3	8.2
R Sh FwBk	99	✓	-8.8	FWD	84.4	39.1	13.3
L Sh FwBk	99	✓	-9.4	FWD	84.4	36.3	12.4
R Sh Hmrl	100	✓	-6.0	LAT	-36.6	22.4	5.8
L Sh Hmrl	100	✓	-5.7	LAT	-36.6	20.8	5.4
Trunk Flx	72	✓	-110.5	FLXN	17.5	137.9	47.6
Trunk Bend	100	✓	-0.7	RIGHT	0.0	122.7	27.9
Trunk Twst	100	✓	0.8	CCW	0.0	46.4	14.0
R Hip	96	✓	-28.3	EXTN	0.3	87.3	33.0
L Hip	96	✓	-28.3	EXTN	0.2	87.3	33.0
R Knee	97	✓	-28.0	FLXN	8.8	71.4	22.9
L Knee	97	✓	-28.2	FLXN	9.0	71.3	22.9
R Ankle	96	✓	-39.0	EXTN	7.0	75.4	20.7
L Ankle	96	✓	-39.5	EXTN	8.1	76.2	20.9

ISS Fitness Center: Motion Capture Technology Testing Packet (page 1 of 3)

Step 1: Review

As a team, carefully review the fitness center design. Look at the dimensions that are included and use the scale to calculate measurements for any areas where measurements are not included. (For instance: Is the space *between* the machines labeled? If not, use the map scale to calculate these measurements.)

Step 2: Analyze

Discuss: What two areas may need extra review from an ergonomics perspective? Try to imagine people using this fitness center, and then highlight or star two areas for testing.

Tip: If your team thinks the overall design looks strong, you may select two areas at random!

Step 3: Prepare

1. With the fitness center plan as your guide, use tape to mark the dimensions of at least one testing section* on the floor. Try to mark the machine dimensions *and* the space around the machine. Also consider the height of the gym—even though you might not be able to mark it!

   *If space allows, mark up both sections that you have selected for testing!

2. Select group members for each of the following roles:

   - **Motion Capturer:** You will film the motion capture technology test.

     Name:_____

   - **Motion Simulator(s):** You will simulate using one of the machines. If you have more than one machine in your testing area, you will need more than one person in this role!

     Name(s):_____

   - **Measurement Controller:** You will make sure the test adheres to the diagram's dimensions.

     Name:_____

   - **Analyzer:** You will record your observations as the testing occurs.*

     Name: _____

     * Remove this role if there are not enough people!

ISS Fitness Center: Motion Capture Technology Testing Packet (page 2 of 3)

Step 4: Motion Capture Technology Testing
To perform the motion capture technology testing, each role should follow these directions:

- **Motion Capturer:** Use your device to begin filming. (Be sure to save the video!)
- **Motion Simulator(s):** Get in position, pretend you are using the machine, and begin moving. If anything feels uncomfortable, share!
- **Measurement Control:** Be sure that the motion simulators remain within the dimensions of their assigned space.
- **Analyzer:** Take notes on your own observations as well as any comments from the Motion Simulator.

Step 5: Repeat Steps 3 and 4 for your second testing area, if needed.

Step 6: Review
Watch the video and review the motion capture technology testing several times. Discuss:

- From an ergonomic and human factors perspective, what worked well?
- From an ergonomic and human factors perspective, what could be improved?
- Considering that physical space is also a concern aboard the ISS, are there any areas that could be made smaller or more compact?
- How could we combine these observations to make improvements?

Step 7: Optimize
Use the grid on page 3 to suggest improvements to the fitness center's design based on the analysis you just completed.

Once you have optimized the design based on your testing results, use the space below to explain the changes that your group made, including what you modified and why.

ISS Fitness Center: Motion Capture Technology Testing Packet (page 3 of 3)

Scale: ——— = _____

International Space Station Redesign Proposal, V2