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Colorado Aerospace STEM Magazine believes that the key to success in seeing higher graduation rates, improved testing results, student inspiration, creativity, excitement and career satisfaction rests in the hands of the teacher. The example and inspiration of individual educators carries tremendous weight on a daily basis, greatly impacting the quality and effectiveness of the classroom environment.

Our mission: Encourage curiosity, investigation, inspiration, creativity, and innovation; the foundations of every career passion and career in the Colorado workforce.

Wayne Carley  
Publisher

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Colorado Aerospace STEM Magazine strives to encourage the educator to better understand the importance of STEM skills, their use in every school subject, the need and ease of integration into curriculum and the urgency for students to embrace STEM.

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We are not saying goodbye to the Hubble Telescope, but rather welcoming a new sibling to the family. Under construction and scheduled to launch in October 2018.
The JWST will offer never before seen resolution and sensitivity from long-wavelength (orange-red) visible light, through near-infrared to the mid-infrared (0.6 to 27 micrometers). While Hubble has a 7.9 foot mirror (light collector), the JWST features a larger and segmented (multi-part) 21 foot primary mirror.

This new telescope project represents an international collaboration of about 17 countries led by NSA, and with significant contributions from the European Space Agency and the Canadian Space Agency. It is named after James E. Webb, the second administrator of NASA, who played an integral role in the Apollo program.

JWST’s capabilities will enable a broad range of investigations across the fields of astronomy and cosmology. One particular goal involves observing some of the most distant events and objects in the Universe, such as the formation of the first galaxies. These types of targets are beyond the reach of current ground and space-based instruments. Another goal is gaining a better theoretical understanding the formation of stars and planets.

**Astronomy Math Exercise**

The fuel capacity is designed for a ten year mission, we hope, compared to over 25 years so far for the Hubble Telescope. The Hubble cost was about 2.5 Billion dollars where as the James Webb has cost 8.7 Billion dollars so far.

Keep in mind that what we see when we look up at the stars at night, are the light and events that happened millions of years ago and that light is just now getting here.

Visible light waves travel at about 670,616,629 mph (miles per hour). How fast is that? A person traveling at the speed of light could circle the earth 7.5 times in one second. By comparison, a person in a jet aircraft, moving at a ground speed of 500 mph, would cross the United States once in 4 hours. The light from our nearest neighbor star, Proxima Centauri, is 4.2 light years away.

**So let’s do the math:** How many miles does light travel in one Earth year?

**Hint:** Multiply light miles per hour (given in last paragraph) times hours in a day times days in a year. The answer is how many miles per year light can travel.

Now multiply that answer times 4.2 and that’s how many earth miles it is to our nearest neighbor star. A really big number (write it down).
Astronomy measures positions, luminosities, motions and other characteristics.

For advanced or really curious students, take it to the next level:

We can only travel at about 24,000 miles per hour in a current space craft with our technology.

So take your answer of how many Earth hours it takes to get to Proxima Centauri,

- Divide by how fast we can go....24,000 miles per hour
- Divide by hours in a day
- Divide by days in a year

Your answer: You get how many of our Earth years it would take to get to Proxima Centauri.
Now that we’ve figured that out, it’s about 70,000 light years to our nearest neighboring galaxy. A telescope sounds like a much better idea.

The JWST will operate near the Earth-Sun L2 (Lagrange) point, approximately 930,000 mi (1,500,000 km) beyond the Earth. A Lagrange point is a location in space where the combined gravitational forces of two large bodies, such as Earth and the sun, equal the centrifugal force felt by the telescope. The interaction of the forces creates a place of equilibrium or balance where a spacecraft or telescope may be “parked” to make observations.

By way of comparison, Hubble orbits 340 miles (550 km) above Earth’s surface, and the Moon is roughly 250,000 miles (400,000 km) from Earth. This is too far away for us to repair it or make changes, so we have to get it right before launch. Objects near this point can orbit the Sun while remaining in a constant position with the Earth, allowing the telescope to remain at a roughly constant distance and use a single sunshield to block heat and light from the Sun and Earth.

This should be a very exciting visual exploration “deep” into space, showing us new and never before seen images of our universe.....gathering lights from about 13 Billion years ago that’s just now arriving at Earth.
Curiosity leads to Exploration that leads to Imagination that leads to Creativity.
Curiosity leads to Exploration that leads to Imagination that leads to Creativity
Engineering, Science and Math can be fun!

José M. López
Col. USAF Ret.
Lecturer MSU Denver
Executive Director Rocky Mountain BEST

As a retired engineer, there are two things that I find worrisome in the 21st Century. First, who will replace me after my retirement, and second, how to show young minds early in their schooling that science can be fun, so that I will not have to worry about the first. One non-profit organization is providing exactly that service at very little cost. Two Texas Instruments engineers started Boosting Engineering Science and Technology (BEST) in 1993. From one team in North Texas it has grown to 17 states and 43 hubs or chapters. BEST provides a free yearly robotics competition for middle and high school students.

How does it work? BEST is an organization that raises funds via grants and donations to provide the materials for the game. In September, we have the Kick-Off meeting in which we unveil the game and issue the materials to each team.
The game is new every year and has a theme. The materials are issued in two totes: one with consumables and a second with VEX electronics. The electronics are reused after the game to keep costs down. From the Kick-Off date, the teams have six weeks to determine a game strategy, design and build a robot, and write an Engineering Notebook describing their efforts. The teams can only use the materials we provide; no going to the local hardware store and buying the BEST robot! The robots are built from scratch and only the students are allowed to manufacture them.

Teachers and mentors provide guidance. By issuing the same materials, wealthy schools have no advantage over poorer schools.

In the 2017 game, Crossfire, the students learn about firefighting. The robot has to “rescue” dummy, move hazardous materials to a safe location, and take out the fire. The dummy is made from PVC, the hazardous materials are empty paint cans, and the fire is simulated by plastic cones. The robots use hollow practice golf balls to simulate the water. The teams have three minute rounds through the day in which they attempt to perform the tasks and score points.

In previous years the teams have tackled
different problems; such as building a power generating wind mill, mining for various commodities, and even robotic farming.

My favorite was WARP XX, celebrating the 20th year of BEST. The students had to build a climbing robot to simulate a space elevator. It required a manipulator arm to pick and move supplies to the space station at the end of the elevator and bring down waste products, both simulated by empty plastic pop bottles. So in reality, BEST is not about a robotics game, but a problem solving exercise.

The 2014 BEST Annual report describes it as “The excitement of a basketball game! The challenge of a science fair! The strategy of a chess match! The pressure of a sporting event!” The program also has an additional, optional, competition called the BEST Award. BEST does not provide funding or materials for this event.

The teams are required to build a booth for game day to explaining the theme of the game. They are also required to create a marketing presentation explaining to a team of judges from industry and academia why their robot design is the best for the mission! This is considered the most prestigious of the BEST awards.

In Colorado, we started the Rocky Mountain BEST hub in 2010 with ten teams and just over 100 students. In October 2017, we had five hubs, with 76 teams, and over 1400 students. SoCo BEST is in Trinidad, Pikes Peak BEST is in Colorado Springs, Golden Plain BEST is in Julesburg, and Front Range and Rocky Mountain BEST are located in the Denver metropolitan area. In 2017 we applied for a regional competition jointly with the Metropolitan State University of Denver (MSU Denver).
It was approved by the BEST Robotics Inc. (BRI) Board of Directors and is scheduled for December 16th and 17th. The best teams from the state will be competing at MSU Denver.

This is not only an event for students. Volunteers obtain a great amount of satisfaction, building the game, training the students and mentors, judging and refereeing the play. MSU Denver students have volunteered, as well as faculty.

Local companies like Verizon, Boeing-Jeppesen, and BEST Buy have provided funding as well as other support. During the summer, Rocky Mountain BEST and Front Range BEST also provide a joint Teachers/Mentor’s Institute (TM)I) two day free program to help mentors, teachers and volunteers understand the BEST program.

Our web site (www.rockymountain-best.org) has links for volunteer participation, video links of the game, and the winners of the 2017 game, among many other things.

**BEST is fun!**
The Boeing X-51 (or X-51 WaveRider) is an unmanned research scramjet aircraft for hypersonic flight at Mach 5 (3,300 mph; 5,300 km/h), an altitude of 70,000 feet (21,000 m). The aircraft was designated X-51 in 2005. It completed its first powered hypersonic flight on 26 May 2010. After two unsuccessful test flights, the X-51 completed a flight of over six minutes and reached speeds of over Mach 5 for 210 seconds on the first of May 2013 for the longest duration hypersonic flight.

Waverider refers in general to aircraft that take advantage of compression lift produced by their own shock waves. The X-51 program was a cooperative effort by the United States Air Force, DARPA, NASA, Boeing, and Pratt & Whitney Rocketdyne. The program was managed by the Aerospace Systems Directorate within the U.S. Air Force Research Laboratory (AFRL).

* Someone has to work on this.

Why not you?
A scramjet (supersonic combusting ramjet) is a variant of a ramjet air-breathing jet engine in which combustion takes place in supersonic airflow. As in ramjets, a scramjet relies on high vehicle speed to forcefully compress the incoming air before combustion (hence ramjet), but a ramjet decelerates the air to subsonic velocities before combustion, while airflow in a scramjet is supersonic throughout the entire engine. This allows the scramjet to operate efficiently at extremely high speeds.
Scramjet Engine

Supersonic combustion ramjets, or Scramjets, operate by burning fuel in a stream of supersonic air compressed by the forward speed of the aircraft. Unlike conventional jet engines, scramjets have no rotating parts. In normal jet engines, rotating blades compress the air, and the airflow remains sub-sonic.
The supersonic airflow into the engine is compressed more as it enters the inlet and passes through the engine. This increases the air pressure higher than the surrounding air.

Conventional Jet Engine

Rotating compressor blades draw in air and compress it. Fuel and air burns and expands in combustion chamber. Gaseous air is forced out the exhaust nozzle, producing thrust.
In the 1990s, the Air Force Research Laboratory (AFRL) began the HyTECH program for hypersonic propulsion. Pratt & Whitney received a contract from the AFRL to develop a hydrocarbon-fueled scramjet engine which led to the development of the SJX61 engine. The SJX61 engine was originally meant for the NASA X-43C, which was eventually canceled. The engine was applied to the AFRL’s Scramjet Engine Demonstrator program in late 2003.

The X-51 is initially propelled by an MGM-140 ATACMS solid rocket booster to approximately Mach 4.5 (3,000 mph; 4,800 km/h). The booster is then jettisoned and the vehicle’s Pratt & Whitney Rocketdyne SJY61 scramjet accelerates it to a top flight speed near Mach 6 (4,000 mph; 6,400 km/h). The X-51 uses JP-7 fuel for the SJY61 scramjet, carrying some 270 lb (120 kg) on board.

**Basic Principles**

Scramjets are designed to operate in the hypersonic flight regime, beyond the reach of turbojet engines (airlines), and, along with ramjets, fill the gap between the high efficiency of turbojets and the high speed of rocket engines.

Turbomachinery-based engines (Turbomachines are wide group of machines, e.g. steam turbines, gas turbines, turbo-compressors, centrifugal pumps/rotodynamic pumps, water turbines and etc.). Their characteristic feature is a rotor with blades on its circumference, which is usually called impeller or runner) while highly efficient at subsonic speeds (slower then 671 miles per hour), become increasingly inefficient at transonic speeds, as the compressor fans found in turbojet engines require subsonic speeds to operate.

While the flow from transonic to low supersonic speeds can be decelerated to these conditions, doing so at supersonic speeds results in a tremendous increase in temperature and a loss in the total pressure of the flow. Around Mach 3–4, turbo-machinery is no longer useful, and ram-style compression becomes the preferred method.
Editors note:
“If you want to go really fast, any type of propeller won’t work. Moving parts just can’t spin fast enough.”

Ramjets utilize high-speed characteristics of air to literally ‘ram’ air through an inlet diffuser into the combustor. At transonic and supersonic flight speeds, the air upstream of the inlet is not able to move out of the way quickly enough, and is compressed within the diffuser before being diffused into the combustor.

Combustion in a ramjet takes place at subsonic velocities, similar to turbojets, but the combustion products are then accelerated through a convergent-divergent nozzle to supersonic speeds. As they have no mechanical means of compression, ramjets cannot start from a standstill, and generally do not achieve sufficient compression until supersonic flight. The lack of intricate turbo-machinery allows ramjets to deal with the temperature rise associated with decelerating a supersonic flow to subsonic speeds, but this only goes so far: at near-hypersonic velocities, the temperature rise and inefficiencies discourage decelerating the flow to the magnitude found in ramjet engines.

A scramjet combustor is supersonic: the inlet slows down the flow of incoming air to a lower speed after which it is accelerated or sped up to an even higher speed through the nozzle.

By limiting the amount of deceleration or slowing down of air, temperatures within the engine are kept at a reasonable level, from both a material and combustive standpoint.

Cold air is usually what keeps jet engines cool as they heat up, but high in the atmosphere where the air is thin, it’s hard to keep them cool. The SCRAM-Jet has a solution to that.

If we are going to replace the Space Shuttle and find another way to get into Earth orbit, the SCRAM-Jet looks like one of the ways we will accomplish that.
Now accepting applications for OAI's 2018 summer internship!
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For more information, visit our website: www.oak-aero.com
There have been two great economic revolutions in the history of human-kind. The agricultural revolution 10,000 years ago transformed people from hunter-gatherers to farmers. The farming lifestyle greatly increased the ability of human communities to capture energy and enabled a hundredfold increase in human population.

The industrial revolution of 300 years ago enabled the economic utilization of energy locked in the earth for 300 million years in the form of fossil fuels. This enabled another tenfold increase in human wealth and population. But the use of fossil fuels and increased human population has put tremendous stress on the Earth’s ecosystem. Furthermore, fossil fuels are limited and will eventually be depleted.

Some view this circumstance with gloom and foresee the collapse of civilization. Others, including many people here in Colorado, are hard at work on the third great economic revolution: space and space resources.

Compared to the finite and increasingly depleted resources on Earth, the resources available in space are essentially infinite. Development and utilization of these resources will enable humankind to continue its trajectory of ever increasing prosperity and well-being while preserving, even enhancing, our unique home in the universe, Earth.

The table on the next page summarizes the major economic revolutions throughout human history, the timeframe, location, the average energy capture per person per day and some of the impacts of the revolution, both positive and negative. The energy capture is measured in kilo-calories. One kilo-calorie is one thousand calories.
Resources available just in the inner solar system are more than enough to fuel the next economic revolution. For example, the energy output of the sun is ten trillion times the current energy consumption of all humanity.

Water exists in great quantities on the Moon, in asteroids and on Mars. Water has many uses including, when broken into hydrogen and oxygen, as rocket propellant. In other words, water is the oil of space, but far more abundant than oil on Earth. Similarly, just a few average sized metallic asteroids contain more metals than have ever been mined on Earth. The potential of space resources is enormous. The challenge is how to get them. What’s required is the infrastructure of a robust space economy.

The first place to begin is cislunar space: the Earth, Moon and neighboring space. For the purposes of this article, I extend this region to include Near Earth Objects (NEOs) or asteroids.

The geography of cislunar space influences the types of economic activities that might take place in various locations. The key locations are low Earth orbit (LEO), Geosynchronous orbit (GEO), Earth-Moon Lagrange point number one (EML1), low lunar orbit (LLO), the lunar surface or a near Earth object (NEO) or asteroid.

Of critical importance is the energy required to move from one location to another. A useful proxy for this energy is Delta V, the increment of velocity that must be added to a spacecraft to

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**Table 1. Economic revolutions through human history**

<table>
<thead>
<tr>
<th>Revolution</th>
<th>Timeframe</th>
<th>Location</th>
<th>Energy Capture</th>
<th>Impact</th>
</tr>
</thead>
<tbody>
<tr>
<td>Evolution of Modern Humans</td>
<td>100,000 years ago</td>
<td>East Africa</td>
<td>4,000 - 5,000 kcal/person/day</td>
<td>Spread throughout world</td>
</tr>
<tr>
<td>Agricultural</td>
<td>10,000 years ago</td>
<td>Levant (hilly flanks)</td>
<td>10,000 - 30,000 kcal/person/day</td>
<td>Increased population, empires, crowding, disease</td>
</tr>
<tr>
<td>Industrial</td>
<td>300 years ago</td>
<td>England</td>
<td>50,000 - 230,000 kcal/person/day</td>
<td>Manufacturing, mining, transportation, prosperity, pollution, climate change</td>
</tr>
<tr>
<td>Space Resources</td>
<td>10-50 years from now</td>
<td>Cislunar Space</td>
<td>Hydrogen / Oxygen propellants, solar power &gt;&gt; 250,000 kcal/person/day</td>
<td>Universal prosperity, green Earth, reduce / clinate scarcity</td>
</tr>
</tbody>
</table>
travel from one location to another. Figure 1 shows the relative locations in cislunar space, the delta V between the locations as well as some of the economic activities that might take place at key locations.

Above: The geography of cislunar space, the key locations, Delta V between them and potential economic activities.
One of the first economically viable uses of resources in cislunar space will be propellant from water. There are several reasons for this. First, one of the most significant findings of space science of the last decades has been the abundance of water in the inner solar system. For example, the permanently shadowed regions near the poles of the Moon harbor significant quantities of water in the form of ice. The photo at the right shows the Shackleton Crater near the south pole of the Moon. Due to the orientation of the Moon relative to the Sun, the bottom of the crater never sees sunlight.

Furthermore, we now know there is abundant water on asteroids and Mars. Second, water has many uses in the space economy, but the most significant near-term use is as propellant. Water’s constituents, oxygen and hydrogen, in liquid form, are the most efficient chemical rocket propellant known.

Finally, space sourced propellants can dramatically reduce the cost of every other activity in cislunar space.

### Cislunar Activity

- Transportation from Earth to Geosynchronous orbit
- Transportation from Earth to Lunar surface
- Cost of a human mission to Mars
- In-space transportation

### Space Sourced Propellant Benefit

- 10-20% lower cost
- 70% lower cost
- 2-3 times reduction
- Essentially the cost of space sourced propellant
To take full advantage of space sourced propellant requires refuelable in-space vehicles. Nothing like this exists today but United Launch Alliance (ULA), headquartered in Centennial, Colorado, is currently developing a new upper stage which will embody all the necessary features. Called the Advanced Cryogenic Evolved Stage (ACES), it includes advanced technology eliminating the need for any fluid commodities other than liquid hydrogen and liquid oxygen propellants. In addition, ULA has perfected the technology and processes to transfer cryogenic fluids from one tank to another under space conditions.

Together, ACES and XEUS form the elements of a fully reusable in-space transportation system that can be fueled by propellants mined from water found on the lunar surface or asteroids. With such a transportation system in place, we can imagine trade routes within cis-lunar space transporting raw materials from the Moon and asteroids to central distribution and manufacturing nodes like EML1, and then down into Earth’s orbit or surface. Due to the enormous energy required to climb out of Earth’s gravity well, once manufacturing capability is established in space,

ACES, shown above, will debut as an upper stage early in the early 2020s. When equipped with a landing kit, ACES can also function as a lander, enabling access to the lunar surface.

The landing version of ACES is called XEUS, shown here in landing mode.
only very high value, low mass items will be transported from Earth to space.

Examples include people and microchips. On the other hand, massless entities like photons have no problem with gravity. Hence, information will be a major export from Earth to cislunar space. This information will take the form of instructions and product designs for in-space manufacturing facilities as well as information to keep the cislunar economy humming along.

Similarly, photons in a form readily converted into terrestrial electricity will be a major import from to earth from cislunar space.

The transportation architecture will be enabling for all other activities in cislunar space. However, the costs to emplace such an infrastructure are daunting. The easy answer is to assume that governments (taxpayers) can be persuaded to bear the expense. But it would be far better if one could devise a commercial business model that would build the infrastructure incrementally while returning profit along the way.

An example of such a business model was developed by ULA based on using space-sourced propellant to ferry satellites from low Earth orbit to geosynchronous orbit. Based on this model, ULA set a price for propellant at the EML1 node of one million dollars per metric ton. This price can now be used by the emerging space mining companies to refine their own business models. In addition, ULA’s analysis was used to derive requirements for a potential lunar mining facility in terms of mass, cost and efficiency.

Once a transportation infrastructure in place, all other activities in cislunar space become much more economical. One of the most important activities for the cislunar economy will be providing energy to Earth. Worldwide
energy consumption is currently on the order of 12.5 terra-watts valued at about $7 trillion per year.

Over 85% of this energy is supplied by fossil fuels in the form of oil, natural gas and coal. These resources are necessarily finite and will grow increasingly more expensive as reserves are depleted.

And unlike terrestrial solar and wind power, space solar power (SSP) is well suited for base load and requires a much less intrusive terrestrial footprint. At geosynchronous orbit, a solar power satellite will receive a daily solar power incidence of 32.8 kW-hr/m². This compares to 7.5 kW-hr/m² in June at my home in Morrison, CO and just 2.5 kW-hr/m² in December.

A concept for a two giga-watt SSP satellite is shown in Figure 5. Called Solar Power Satellite (SPS) Alpha, the concept was developed by John Mankins under contract to NASA. It is a very large object, measuring 3km by 5km and with a mass, if launched from Earth of 12,000 tons. At today’s prices, just the launch costs would total $320B—clearly un-affordable.

If one can source most of the raw materials on the moon, manufacture the components at EML1, and assemble it in place at GEO, the economics move into the realm of feasibility. All transportation is assumed to be provided by ACES and XEUS. The total non-recurring cost as well as the development cost per kilowatt of capability is comparable to a large scale nuclear powerplant and well within the resources of large commercial power companies.

Yet, the assumptions are challenging
and require the development and establishment of large scale space mining and manufacturing infrastructure. But once established, this infrastructure can enable the construction of hundreds of solar power satellites, reducing and eventually eliminating our reliance of fossil fuels while enabling increased prosperity through inexhaustible, carbon-free, low cost energy.

Students in Colorado with a strong interest in STEM are extremely well positioned to participate in this next great economic revolution. Our major universities offer cutting edge programs in science, engineering and math that will provide exciting jobs in space related fields. CU Boulder is among the world leaders in planetary science and aerospace engineering. The Colorado School of Mines has recently announced the first ever graduate program in space resources, bringing its expertise in finding and developing Earth resources to the realm of space.

Many of the world’s foremost space companies call Colorado home. From Lockheed Martin to ULA, Ball Aerospace to Sierra Nevada and smaller companies by the hundreds, Colorado is home to the highest per capita population of space professionals in the nation.

Interest in developing the cislunar economy is expanding around the globe as companies and governmental agencies begin to realize the incredible potential of the next great economic revolution for humanity. Vice President Pence has just announced that America is going back to the Moon to stay. The transportation system will be the first economically viable sector of the economy to be established. It is enabling for everything that follows. The capstone will be space solar power, tapping into the enormous worldwide energy market and providing benefits to billions of people on Earth.

Don’t you want to be a part of it?
The Author:

Dr. George Sowers has 30 years of experience in the space transportation field working for Martin Marietta, Lockheed Martin and the United Launch Alliance (ULA). He recently retired from his position as Vice President and Chief Scientist at ULA where his team developed an architecture for fully reusable in-space stages fueled by propellant mined, refined and distributed in space.

Dr. Sowers has now joined the faculty of the Colorado School of Mines as part of a newly created graduate program in space resources. He holds a BS in Physics from Georgia Tech and a PhD in Physics from the University of Colorado. Dr. Sowers is a fellow of the American Institute of Aeronautics and Astronautics (AIAA).
Can STEM Education Actually Prepare Our Children for the Future?

By Eliot Kersgaard and Ted Thayer
Co-founders of Myra Makes, Colorado

Student disengagement in the United States has been worsening for decades, with only half of US students reporting engagement at school (Brenneman, 2016). We’re warned that our students are falling far behind other nations in science, math, and literacy.

The response from education policy makers? A heat, beat and treat approach of more tests, longer days, and slashing the arts and humanities. Our school systems have devalued different ways of thinking and being, forcing students to conform or fail. Students are caught in a vicious cycle whereby low engagement inhibits performance, causing us to more rigorously enforce practices which further exacerbate disengagement.

All the while, the need for youth who are equipped and excited to tackle global challenges has never been greater. Is STEM education the answer to the urgent need for a new generation of engaged innovators?
At Myra Makes, our answer to this question is “not quite.” When we first set out to empower elementary schoolers as tomorrow’s innovators, we believed that inspiring kids with a love of STEM would help them become the problem solvers of tomorrow. In our first class we led elementary kids through a variety of activities meant to build interest and ability in spatial visualization and other STEM skills through story-based worksheets. Myra, our main character, was the key to unlocking kids’ interest in these subjects.

We noticed the kernel of something that would guide our journey from that moment forward. Kids rejoiced in participating in an adventure, applying their knowledge toward helping others, and creatively collaborating with one another. We began to focus our efforts on creating environments, through in-person edutainment experiences and a learning adventure book, that would encourage self-direction and makership.

Of course, we haven’t been the first ones to hit upon the magic of participatory experience. In our exploration of how this has been done in Colorado, we’ve found the maker movement to be one of the most vital in a growing ecosystem that places self-actualization and creative empowerment at the center. Effective maker development is inclusive, requiring us “to work effectively with people who define problems differently” (Downey et al, 2006), and “understand the social and emotional needs of kids where they’re at”, said Michael Alcazar, Systems Designer, UpDig.

Further, in order to meet the social and emotional needs of all youth, “making must now be about healing. It’s each of our tasks as makers, engineers and designers to figure out what that means and how to do it for ourselves” (Kendra Krueger, Community Science Consultant, 4Love+Science, 2017).
"Understand the social and emotional needs of kids where they’re at."

The mindset and skills involved in making are more fundamental and more practical than the competencies of STEM. The National Association of Colleges and Employers (NACE) surveyed 260 corporations for the most sought after skills in new hires. Not until #6 did a technical skill enter the list (“Ability to obtain and process information”), while “Technical knowledge related to the job” came in at #8.

The top choice was “Ability to work in a team structure,” with “Ability to make decisions” and “Ability to solve problems” tied for second (Adams, 2014).

These top three skills are all core elements of making and support STEM in the real world. Sadly, they are rarely explicit in curricula, and only “Ability to solve problems” appears in the Next Generation Science and Engineering Standards (NGSS Lead States, 2013), and even then, only for engineering, not science.

So how do we teach teamwork, decision-making, and problem-solving? We don’t-- we participate in it. We can’t “teach” teamwork to kids, but we can be their teammates. Placing students’ unique interests, abilities and cultures at the center of education is the starting point to “[realize] the promise of a fair and just society, [which] hinges on a psychological transformation” (Gilligan, 2013, p. 122).

Over the last two years putting this belief into practice, we’ve learned one simple lesson: minimizing structure is key. Minimizing structure maximizes possibility, resulting in more creative solutions and more empowered living. To minimize structure in our offerings, we’ve asked ourselves, “What questions can we ask that open up the most opportunity?”

Too often as adults we limit ourselves with assumed models of what’s possible, leading to efforts that fall short of their potential. Looking past the boundaries of our models from education to engineering opens space for rethinking problems, a gateway to vastly greater returns. It also gives us the flexibility to transfer our skills to new domains.
In today’s shifting and interdisciplinary world, society needs innovators who can look at problems differently and adaptively respond to changing conditions. The STEM movement attempts to address these needs, but needs to include more creative, open-ended, and democratic practices to truly fill the role.

Last Spring, we had the privilege of sharing a 60-minute period with a 5th grade math class at Prospect Valley Elementary School in Wheat Ridge, Colorado. We asked them three simple questions: What are your favorite things to do? What are your favorite things to learn? And how do you like to learn best?

The students self-organized into groups and worked together to combine the results from these three questions into a new way to organize their education. The results were profound, not due to their complexity or detail, but due to their simplicity. Again and again, kids wanted to learn technical skills like coding, mathematics, or science through non-technical means such as sports, games, and art. Upon naming these combinations, students worked together to help each other brainstorm fun, new ways to bring their passions together.

Results such as these demonstrate how participatory, student-directed learning can bridge historically isolated disciplines and advance learning beyond what more structured environments allow.

We believe that democratizing education through making is essential to answer the need for a new generation of innovators. It will be a generation in which people uplift one another in supportive play as they walk toward their unique visions for a better world.

Play is the unfolding of freedom, possibility, and creation. It’s built into our DNA-- all young mammals engage in unstructured play, with great benefits in adulthood (Whitebread, 2012).

People are distinct amongst animals in that our playfulness often continues to be a part of daily life in adulthood (Brown, 2008). Through facilitating playshops and giving away activities to families and schools, we’ve seen first-hand how play helps us learn (and create) the rules of engagement, explore the world, and invent new possibilities. Play is an activity in storytelling and make-believe, crafts which usher new realities into existence.

Sadly, somewhere along the way, too many of us become conditioned to strictly differentiate between the make-believe and the real, never realiz-
ing that the real is constantly redefined and recreated. What would happen if the line between the possible and the impossible stayed blurred throughout life?

We would create a generation of makers, engaged with a continual process of transformation and pushing the boundaries of how we interact with spaces, objects and one another. We would leverage the essence of makership, the internal drive to actualize that which has never even been imagined before. This grants the maker the fantastical power of seeing the future. Makers become involved (sometimes obsessed) with an ongoing, cyclical process of creativity in which failures become opportunities and problems become solutions.

Unlike what we too often see in standardized STEM education, effective making is messy, unpredictable, and unteachable. Working with those qualities on our side, educators, entrepreneurs, and parents can support budding makers with accessible spaces, flexible leaders, helpful resources, and good questions.

In **Colorado**, these support systems are flourishing. With makerspaces in libraries and schools, pioneering companies such Colorado’s Brackitz building system, and family-friendly, maker-focused events, there are few other places where kids have a better environment to dream. We have seen the humbling results of prioritizing self-actualization and play right in front of us, from a girl telling the whole crowd at a fundraiser that they “loved problem-solving adventures,” to stories of siblings who “play Myra Makes” at home, creating their own characters, challenges and solutions.

If you’re also embarking on this adventure to empower children as makers, please reach out. We’d love to hear about your journey and work with you to make a better future for all.

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**References**


Three Types of Innovation

- **Rethink**
- **Redesign**
- **Incremental Change**

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What fraction of seats offered for sale each week by your local movie theater are sold to customers? Think for a minute before proceeding.

Many people estimate 40% or 50%. In fact, many of you might have been turned away recently from an opening weekend of a blockbuster film, so you might even guess closer to 100%. Well, the typical correct answer across the USA is about 5%. That’s right, about 5% of all movie theater seats offered for sale during a week are actually sold to paying customers. How can this be, when all we see is nearly filled theaters? The answer is that most of us go to see films on Friday and Saturday nights, when the seats are relatively filled, not the Tuesday 11:00 AM showing when you might be the only customer in the theater.

Your own appearance during busy times creates a significant selection bias. You as customer experience a busy theater. The owner of the theater sees 95% empty seats. Both are correct.
Our ability to reason properly with numbers and statistics. We need to be knowledgeable interpreters of data-informed situations. We need to read statistics-laden reports with appropriate skepticism. Recent news articles have created some controversy over the national need for emphasis on STEM education, the reports suggesting that we now have an over-abundance of Ph.D.s’ with science degrees and that graduating engineers do not do actual engineering for very many years during their careers.

It is true that some science-trained Ph.D.s’ are unemployed and that many with degrees in engineering go off and do other things, often within a few years of graduation. It’s also true that we currently have hundreds of thousands of STEM-focused job openings.

Many apparently non-STEM jobs have become STEM jobs, especially in the trades. Do you know that the average new car has about 50 microprocessors? Forget about crawling under it with a few of your Dad’s tools to fix it! And Moore’s Law of computers has affected most other trades as well. But perhaps the most important reason for everyone to become STEM literate is to build a more informed citizenry. In that way we individually and collectively become better decision makers about all the options that a democracy faces.

STEM is not only for Ph.D. researchers. 

It’s for all of us!

“We all need STEM thinking skills.”

But my point is this: Becoming knowledgeable about STEM is not about the 0.01% who might become Ph.D. researchers or the 2% who might become engineers. In this data-informed, technology intensive 21st Century, the entire populace needs to become STEM literate. We all need STEM thinking skills.
Science Island (Part 1)

Dr. Brad McLain
XSci
University of Colorado, Boulder
As someone who has spent all of his adult life, roughly the past twenty four years, in the field of science as both a researcher and an educator, I have had the good fortune to deeply explore how science works across a wide range of specific disciplines as well as how it is commonly communicated by scientists and science educators to their students and to the public.

Long ago, I encountered the issue that ultimately led me to my current research into science identity construction. Simply put, while most science education efforts and assessments are preoccupied with content and addressing science misconceptions in terms of content, there is a much more fundamental and problematic undercurrent that is harder to detect and address – the misconception of science itself.

Erroneously, we as a society do not see science as a human endeavor and rarely consider or communicate how it fits within the larger humanistic experience.

To illustrate the dehumanization of science, I offer a true story that will be sadly familiar to many of you…

I was somewhere over the expanse of the Pacific Ocean, at an altitude of perhaps some 30,000 feet in a Boeing 737. I had earlier embarked on a competitive round of the popular 1980s video game “Galaga” on my iPad with the gentleman sitting just across the narrow isle. After a bit of friendly gameplay banter, eventually the conversation turned to our mutual reasons for traveling to Hawaii.

While he was on a family vacation (his family was seated all around us), I explained my purpose was to present at a conference as part of a National Science Foundation project on the seemingly unlikely marriage of science and storytelling.

“Oh, science; I was never any good at science,” was his response. As I often do in such conversations (which I have with disturbing frequency), I pressed him for some details and asked what he meant. “In school, I got good grades... History, English, Social Studies... but not in Science. Science lowered my GPA big time. I couldn’t do it. I didn’t understand it.”

He said all this without a hint of self-consciousness – quite the opposite.
Many times in these conversations, the “I’m no good at science” refrain is recited almost as a badge of honor, even a kind of social bonding agent. Far from being shocking, they are more the rule than the exception.

I pointed out that surely there must be some level of science involved in his business; after all in today’s society it is hardly possible to escape the influence of science and technology. “Not if I can help it,” he said, laughingly, expressing his active avoidance of the topic. And to cap the moment... “I hate science.”

Later as we began our descent into Honolulu, I pondered exactly what it was he thought he hated. There is so much in science that inspires wonder and curiosity; that equips us to become shrewd seekers of fact, discerning it from wishful thinking; that provides us with the tools to ask the big questions and unlock the mysteries of the Universe we inhabit.

Was it actually science he hated... or some conceptualization he had assigned to “science” based on his experiences? And where were those experiences likely to have occurred? School, it would seem from his comments. And from that, how did he perceive science? How do most people?

This of course is a central concern to science communicators, science educators, and scientists themselves. And it should be of central concern to all of us. I began to reflect, what do the words “science and technology” represent to people that make them so mysterious, intimidating, or undesirable?

For scientists, this is of course not true; we were somehow able to navigate our way to a scientific worldview despite a societal “science-phobia.” But for the vast majority of people, why is science taboo? What is it about science that excludes so many people? Why do people exclude themselves from it?

With the coastline of Hawaii emerging through the clouds below, I indulged in a curious flight of the imagination; a maritime visit to “Science Island...”
The journey had been long and difficult. We had prepared our little boat as best we could, investing it with all our knowledge and skills to make it a seaworthy vehicle, capable of carrying us safely over the open ocean of intellectual concepts and experience.

We had been told that somewhere out there was the remote Science Island; a place of wonders and discovery, a place where people from all nations tirelessly searched for answers, forging hope for all of humanity. And we had a map and means of navigation – we knew the general heading and kept our stars about us until at last, its rocky shores emerged from the mist.

As we neared, a small chain of lesser islands in the archipelago came into view. These were the “Pseudoscience Islands” and our navigation through them was tricky with many wayward eddies and currents. But finally, through rough waters, we approached the high foreboding cliffs of Science Island itself. It was most uninviting, with no discernible good ports of entry or safe harbors that we could find. No welcoming points of access. Clearly we would need our guide (Science Teacher) to bring us in safely.

Though quite seasoned with many trips between Science Island and the mainland, our guide brought us in for a rough landfall as the crashing surf battered and bruised our little boat. Once on the beach, we noticed the island was surprisingly small for having such global influence – not many people could have been living there.

The terrain was rough and unfamiliar, and the initial going was difficult underfoot. Eventually, we ascended into the thick “Jargon Forest” of the highlands. It was overgrown with dense, nearly impenetrable foliage. But our guide expertly hacked out our path with a linguistic machete and we slowly made way despite many scrapes and scratches.

Up until then, we had seen no natives, only a few of their foundational structures, historical writings, and some
monuments to their esteemed heroes. However, our guide ventured ahead for a spell and returned sometime later with a rather surprised and bewildered-looking Islander from a nearby village. He bid us welcome to the Isle and spoke nervously and not a little defensively of the important work they were doing there. He then invited us to the village for a first-hand look.

Finally, we came upon the central forum of the village where a lively debate was taking place. To our astonishment, they were speaking to one another in a totally unfamiliar language – not English, nor French, nor Spanish nor any other language we could recognize. Even our guide was baffled, though not surprised.

As the argument continued, it grew increasingly hostile and we were shocked at the intensity and apparent lack of basic decorum of the proceedings. At one point, I raised my hand to venture a question of the combatants only to be coldly and embarrassingly dismissed for my lack of scientific acumen. Our guide simply smiled, “This is just the culture of Science Island. And this is one of the peaceful domains. In other areas some tribes are even cannibalistic.”

At this, our horror was complete and we quickly vacated the scene and soon thereafter left the Island in our wake. Stay tuned … in Part 2 of “Science Island” we will unpack science phobia and negative science identity.

The village itself was a strange place. For one thing, there was very little sound as we walked down the main street, even though we could see several sets of reclusive eyes peering at us suspiciously from behind trees or within buildings. But generally, no one was talking although they all seemed quite busy. Secondly, a few gruff-look- ing characters walked right passed us without so much as a friendly smile or gesture of any kind, in a world of their own.

Dr. Brad McLain is the co-director of XSci (Experiential Science Education Research Collaborative at the University of Colorado Boulder) www.XSci.org
Success on Standardized Tests Without Sacrificing Authentic Learning

By Judy Willis, M.D.

“Algebra is a way of arranging knowns and unknowns in equations so that the unknowns are made knowable. The three fundamentals involved...are commutation, distribution, and association.

Once a student grasps the ideas embodied by these three fundamentals, he is in a position to recognize wherein ‘new’ equations to be solved are not new at all. Whether the student knows the formal names of these operations is less important for transfer than whether they are able to use them.”


Concepts and Memory

Grasping the structure of a subject is understanding and holding it in a relevant memory category. This becomes a neural network that be used for transfer, where it can link with other networks for application beyond the original learning situation.

Constructing neural networks is achieved not by rote memorization, but by mental manipulation where new input and prior knowledge are related meaningfully. Concept knowledge in math is the authentic way of achieving long-term memory and is best achieved by learning how things are related.

Long-Term Memory Building and Maintaining

Repetitive stimulation of the neuronal circuits holding the information is necessary for the memory to be maintained and even for the neuronal connections to remain in place and not be pruned. The mental manipulation and active processing of learned information through the executive functions especially Practice really does make permanent – as long as the practice involves active mental manipulation, construction of new ideas, and truly using the new information in different ways that it was originally learned.
Mental manipulation is not what happens when students passively repeat procedures over and over on worksheets.

For example, when students review learned material by solving well designed word or story problems, they are making judgments in the prefrontal cortex stimulates memory circuits. It is these networks, activated during mental manipulation of the new information through prioritizing, comparing/contrasting (similarities/differences), deduction (constructing new knowledge from existing information), and induction that stimulation of the memory storage areas increase the strength of the neural networks through additional dendrite sprouts, more synapses, and thicker myelin around axons that speeds transmission between neurons.

Practice really does make permanent – as long as the practice involves active mental manipulation, construction of new ideas, and truly using the new information in different ways that it was originally learned. Mental manipulation is not what happens when students passively repeat procedures over and over on worksheets.

For example when students review learned material by solving well designed word or story problems, they
are making judgments about what question is being asked, analyzing the data provided to determine what is needed to reach a solution and what is extraneous, and considering the procedures the know to see which might be useful.

To carry out these executive functions there is information exchange from the executive function networks to the areas of stored memory in categories deemed relative to the problem. These stored memories are found throughout the various lobes of the brain depending on the different sensory modalities that carried the input into the brain. If the knowledge was acquired through multi-sensory learning and review, there is activation in the visual, tactile, auditory, and kinesthetic input receptor cortexes when the problem is considered.

Similarly, when learning is reviewed by authentic incorporation in new learning, the storage circuits are reactivated. For example, each time a long division problem is done correctly there is practice of subtraction and multiplication. When learning is examined through follow up lessons using open-ended discussions, students are encouraged to seek multiple approaches to solving problems and to verbalize and communicate with classmates.

This provides opportunities for more student engagement. When classmates add new approaches to the problem solving, the other students extend their established, stored memory patterns and categories to incorporate the new insights.

It is not only neuroimaging evidence of multi-centric brain cortex activation (metabolism) during problem solving, but also of activation of emotional networks throughout the limbic system that can be stimulated by problem solving. These areas that are important in memory consolidation and retrieval such as the amygdala, hippocampus, and basal ganglion can be “exercised” and receive increased blood flow and neuronal network fortification when the stored information is associated with positive emotional experiences.

These are the activities described earlier as having a beneficial influence on the amygdala and dopamine release related to pleasure and enjoyment influence on memory when these activities are incorporated in the teaching or review.

These are the powerful lessons you create to incorporate personal interest, prior knowledge, global real world connections, surprising discrepant experiences, and the intrinsic reward of achieving challenges the students feel are significant.
Long-Term Memory Building
Through Concept Review

Building and retrieving memories takes place in stages through information encoding, storage in patterns of relational memories, and restimulating these neuronal pathways by review each time the memory is accessed and used. Familiarity increases recall so students with memory-based learning difficulties can preview the coming lesson by skimming the new section in the book before class. In that way, when they hear the new terms they will have had at least one initial exposure to them. When recall seeing a word on the pages they previewed, even if they don’t remember any details or understand its meaning, just hearing the somewhat familiar term or procedure will increase activation in their cerebral cortex.

On fMRI scans when the brain even recognizes a word, even without knowing its meaning, there is enhanced activity in the anterior left prefrontal, left parietal, and posterior cingulate regions. This previewing or priming front-loads or preheats the brain’s related memory patterns or categories and there is less stress from unfamiliarity when the lesson is taught.

Similarly, in class before the lesson if you write and say the new terms, important concepts, or major themes that will be taught that day in math, students’ associated and relational memories connected with the new information will be “on-line” and ready to be retrieved to the hippocampus for consolidation with the new information they encounter in the day’s class.

When you help students understand the terms and concepts being discussed throughout the lesson, they can devote more working memory to processing and analyzing ideas, making connections, and actively processing the new information and less working memory will be needed to simply decode new terms.

Similarly, when learning is reviewed by authentic incorporation in new learning, the storage circuits are reactivated. For example, each time a long division problem is done correctly there is practice of subtraction and multiplication. When learning is examined through follow up lessons using open-ended discussions, students are encouraged to seek multiple approaches to solving problems and to verbalize and communicate with classmates. This provides opportunities for more student engagement. When classmates add new approaches to the problem solving, the other students extend their established, stored memory patterns and categories to incorporate the new insights.
When skills and facts are taught and practiced as part of solving complex, interesting, meaningful problems, the learning is richer; confidence and relational understanding develops in a context of meaning. By engaging students through personal interest and real world use of the procedures and rote memory facts that are the basis of future learning, they feel the learning is useful and worth their effort. When students see the value of what they are asked to learn they are motivated to build the foundations they need to achieve personally meaningful goals.

Of “risk-taking behavior” that can stimulate the dopamine-pleasure response and encourage fearful or perfectionist students to take chances without the anxiety (amygdala stress) of being wrong. Emphasize that predictions don’t have to be right. They are an opportunity to pose questions and see what the outcome is. Learning through inquiries and discovery is more motivating, successful, and less threatening when students know what basic arithmetic they need to know at the automatic level.

“Gain student interest with a provocative question...”

Knowing how memorizing multiplication facts so they become automatic helps student motivation because they understand why it is worth their effort to rehearse these facts until they are mastered.

When they participate in inquiries and investigations along with procedural learning they realize how having these tools easily accessible makes the investigations and problem solving more enjoyable and less threatening.

Gain student interest with a provocative question and discussion about the coming unit. At the start of a unit, ask whole-class prediction questions that can be responded to at different, creative levels in personal journals. Once predictions are written down, students will be more invested in learning more about the topic to see if they are right. Making predictions is a very safe type of “risk-taking behavior” that can stimulate the dopamine-pleasure response and encourage fearful or perfectionist students to take chances without the anxiety (amygdala stress) of being wrong. Emphasize that predictions don’t have to be right. They are an opportunity to pose questions and see what the outcome is. Learning through inquiries and discovery is more motivating, successful, and less threatening when students know what basic arithmetic they need to know at the automatic level.

Their affective filters will open up to the pleasure of creative mathematics. Students with limited experience in the mental manipulation that builds relational memory will not build the skills of creative problem solving, concept development and communication, pattern recognition and predicting, and other forms of prefrontal lobe executive function cognition they need to
use reason, logic, and extension of patterns and procedures for the daily complexities of life or the professional jobs of their future.

**Activities that Reach Executive Function**

- Create a web page or power point presentation
- Design a board game
- Write a book for a younger student
- Create a brochure or advertising materials
- Make predictions based on the knowledge
- Connect to another subject or big idea
- Use the information to try to help solve a meaningful problem.
- Write a letter to the editor of the newspaper about calculations you made about where energy use is high and what changes could result in reductions you mathematically predict.
- Create a newsletter or blog with your position.
In the field of aerospace and science there are many players competing in the pursuit of space. Since the early days of the lunar program, public-private partnerships have been at the forefront of that pursuit, in bringing together the best of industry, academia, and government have to offer. Today is no different with many partnerships being formed in Colorado to help foster innovation, growth and continue the pursuit of space.

Colorado’s Growing Universities

With so many entities wanting a piece of the space pie, it is no secret that some of Colorado’s biggest universities are building their own aerospace buildings. At the beginning of 2017 Metropolitan State University of Denver opened up their own 142,000 square foot facility opening up a whole new realm of engineering for MSU students.

And now, CU Boulder is not far behind with plans to build a 139,000 square foot aerospace engineering building. Building is set to begin in the fall and will help the College of Engineering and Applied Science enhance its reputation as being one of the top leaders in aerospace education and research.
Continued efforts by universities like CU and MSU allow students to remain in their home state and maintain a competitive education at a lower tuition. Both buildings will house various aerospace programs and provide the very best education has to offer. In addition to housing CU’s six aerospace engineering clusters, the new building will also feature an indoor flight environment for testing unmanned aerial systems.

In a recently released strategic vision, CU Boulder Dean of College of Engineering and Applied Science stresses the importance of building on progress that has been made in the past decade. Their strategic emphasis on leadership, innovation and positive impact will allow CU Boulder to grow its national leadership role in engineering education and research as well as improve its economic competitiveness, security and quality of life for all Coloradans.

Universities are growing and morphing into so much more than higher education. Part of the College of Engineering and Applied Science’s strategic vision is to become a world class research institution. They seek to provide technical solutions to pressing societal challenges as well as bring colleagues together in interdisciplinary collaborative spaces to space innovation and accelerate discovery.
Creating partnerships between public and higher education will also be a focus. Already one of the top aerospace engineering schools in the country, the College of Engineering and Applied Science will create an environment that invites engineering students both in the Centennial state as well as students from across the nation. There are already plans in place to grow their undergraduate and graduate programs to support the economic growth of our state.

**Colorado Industry**

With local universities growing and Colorado maintaining its rank of 2nd in the Nation, more and more partnerships are occurring. In 2016 Oakman Aerospace, Inc. (OAI) came together with the University of Colorado to sign a Master Services Agreement (MSA), allowing either entity to act as the contracting or servicing party to execute task orders. The partnership created between OAI and CU Boulder has opened up many doors for both. For Oakman Aerospace, it has allowed greater collaboration efforts as well as allowed partnerships to support AeroSpace Ventures (ASV) inspire a new generation of STEM innovators. As an industry partner, OAI is able to attend such events as AeroSpace Ventures Day. Each year this event is held to bring together Colorado’s leading aerospace companies, small businesses and
The event also acts as a career fair and networking event for CU students. OAI was proud to exhibit our 2017 summer internship program, in which OAI partnered with the Eastern Upper Peninsula Intermediate School District (EUPISD) to create and launch a 9 week after school rocketry program.

As the CSC website says, “Colorado Space Coalition members span the entire state, representing diverse backgrounds, but united goals.”

For more information on the Colorado Space Coalition or to become a member, please visit:

http://www.spacecolorado.org

Colorado’s central location made it less vulnerable to enemy attacks during the Cold War, allowing it to become the hub that it is today. And for what it is worth, the first mile to space is free!

Colorado Governance

Colorado is the nation’s second largest aerospace economy, containing operations from 8 of the nation’s top aerospace contractors. On any given day there are over 400 aerospace companies just in the state of Colorado offering over 188,000 jobs. With numbers like that, it makes it hard to deny that Colorado really is one of the best places to be.

One of the most prominent space organizations that is constantly governing Colorado’s involvement is the Colorado Space Coalition (CSC). Made of industry stakeholders, the CSC works to make Colorado a center of excellence for space, and maintain Colorado’s space industry. They are continually collaborating with local legislation to expand industry as well as market and promote current programs, and allow for networking and collaboration between other aerospace companies.

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Oakman Aerospace, Inc.
COLORADO is STEM