STEM Education at Shaftesbury High School—A Brief History

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Abstract

SHARP and SATS are extra-curricular Science, Technology, Engineering and Mathematics (STEM) projects at Shaftesbury High School in Winnipeg, Canada. Students involved in SHARP receive a STEM education as they design, build, test and fly aircraft including high altitude balloons (HAB's). The need to track the HABs in flight led us to the APRS (automatic packet reporting system) and amateur radio. This resulted in a need for student radio operators so SHARP began to work with the local amateur radio club to provide certification courses at the school. Twenty-four call signs have been issued to the students and staff at Shaftesbury in the past four years. This activity came to the attention of Stefan Wagener, a local member of AMSAT. Stefan made us aware of ARISS and suggested that Shaftesbury High School build an ARISS telebridge station. We agreed and the station was completed in August 2014. Students will use the station to "work" satellites and to acquire and process telemetry from high altitude balloons and satellites. SATS students will learn hands-on about radio communications and orbital mechanics. The authors will give a brief history of these two non-curricular projects, SHARP and SATS, and provide our perspective on the state of STEM education.

Amateur Radio Arrives

In 2009, the teacher librarian[i] at our small public secondary school, challenged the science teachers including the authors to fly a high altitude balloon (HAB) to the stratosphere in order to take pictures of space as he'd seen on a YouTube video. After some online investigations, the authors decided it would be possible for our students to design and build a HAB payload that could record images of space from an extremely high altitude. As this kind of activity did not fit with provincial science curricula, the project had to take the form of a noon-hour and after-school activity. Our next step was to take the idea to the students. Would there be enough interest to justify the effort? Would students give up their spare time to fund raise, design, build, test and fly the balloon and payload to the edge of space? Absolutely! As it turned out, we had 30 students from grades 9 – 12 (ages 14-18) of all interests and abilities more than willing to take up the challenge.

Fundraising for the project began quickly. A writing team was formed to complete grant applications and write letters requesting financial support. Other teams were formed including imaging, science and electronics teams. The teams worked independently but we all gathered together once a week to coordinate the overall effort.

Initially the teachers were unsure of the best way to track a high altitude balloon. How would we get the camera back from space? We discovered that the most commonly used method, at least in North America[ii], and the method we chose, was to use an amateur radio system developed by Bob Bruninga (WB4APR) called APRS (Automatic Packet Reporting System). We would need an APRS beacon and one or more certified hams at the school to turn on the transmitter. This was the beginning of our ongoing amateur radio adventure. While our students set about acquiring knowledge, designing a payload, sourcing materials and writing letters to potential donors, some of us also took amateur radio classes on the weekends.

The Shaftesbury High Altitude Robotics Project

The project required a name. We soon started calling it SHARP for Shaftesbury High Altitude Robotics Project. SHARP is an extra-curricular activity. It runs every day over the lunch hour and sometimes after school and on weekends. The teachers decided from the outset that the students must, to the greatest extent possible, drive the project and do the hands-on work. The teachers would act as mentors and facilitators. The project survives only by the interest demonstrated by the students. Therefore, all members are motivated volunteers.

Back in 2009 we did not know that HAB flights were actually quite common. We were surprised when we found out there was a group in Winnipeg that had experience with HABs and APRS tracking called WinCube[1]. In the summer of 2009, some of us attended a Space Camp for high school students put on by Dr. Withold Kinsner (VE4WK) of the University of Manitoba's Department of Electrical and Computer Engineering and a founding member of WinCube. Through the Manitoba Space Camp[iii], and also WARC (the Winnipeg Amateur Radio Club), SHARP made some valuable contacts but at this point none was more important than Alan Thoren (VE4YZ) who became our chief mentor. Alan also donated much hardware to SHARP including amateur radios, antennas and power supplies.

During the 2009-10 school year the teams were making progress. Money started coming in. Materials were purchased such as a soldering station, a weather balloon, plumbing supplies and a helium regulator for filling balloons. The payload team learned how to solder and make precise cuts in foam board insulation using a hot nichrome wire. Three of us became certified amateur radio operators. In the spring of 2010, SHARP purchased a Byonics APRS transmitter and a Garmin GPS-18 receiver for the HAB payload and a Kenwood TM-D710A dual band mobile transceiver and AVMap GPS navigator for the chase car. Bruce Feaver (VE4BDF), a commercial pilot and former Shaftesbury student, provided us with a lesson in parachute design. Later, Bruce provided the 24 inch parachute itself. Bruce also became the Operation Manager. One task he took on was filing the HAB flight NOTAMs with NAV CANADA. Other hams helped in various ways.

The SHARP team was ready to fly its first high altitude balloon by October of 2010. Given the predicted winds aloft, we decided to field trip the SHARP team 220 kilometres northwest of Winnipeg and launch near a resort at Elkhorn Manitoba. The resort would be our base away from school. Twenty students and four teachers arrived at the lodge on October 21st and immediately set up a shop to prepare the payload for launch in the morning. The next day, SHARP-1,[iv] a 1500 gram helium filled balloon, parachute and payload lifted off from the nearby Erickson aerodrome. The chase that followed was very exciting. The balloon reached an altitude of 107000 feet. Three and a half hours after launch the payload returned to the ground just outside the city of Winnipeg and just 18 km from our school. Our students opened the payload box together and they were overjoyed when they discovered the camera was still recording video.

The SHARP 1 payload was loaded into a car and we returned to the school. By the afternoon we were all watching the flight video projected onto a large screen.

Watching the video, we felt as if we were onboard the balloon. We saw the pre-launch activity. After the countdown, the ground started to pull away. Fields and trees, roads and lakes appeared and then shrank until it seemed we were looking at a large map. As the familiar sounds of the Earth slowly faded away, blue sky slowly changed to black. Eventually we saw the curvature of the Earth from an altitude of over 32 kilometres. We had arrived at our destination – space. Then the balloon burst and the payload tumbled down. The rotation rate increased at an alarming rate. The payload underwent a violent and chaotic period of free fall through the near vacuum of the stratosphere. The sound of rushing air was now heard along with a banging sound made by the beacon's antenna as it was whipped against the side of the payload. Slowly the attitude stabilized and the descent slowed. Finally, we swooped over a deserted field and landed. After some time, feet and legs appeared. Students excitedly gathered around their "spacecraft". The payload was opened. The camera was still recording.

Figure 1. The success of SHARP 1 generated enthusiasm for amateur radio.

There was joy, excitement and pride all around. A year of team work had paid off. The video was proof that we could reach space. The students immediately expressed their enthusiasm for more HAB flights. We were immediately hooked on ballooning and amateur radio.

Figure 2. Students prepare a rockoon (rocket-balloon) for GPS/Arduino controlled launch. Satellite tracking antennas are visible on the school roof.

The students felt they could take the technology much farther. Their ambitions grew and so did the size and complexity of their payloads. Two more successful flights followed in years to come. SHARP 2 flew in 2011 and reached an altitude of over 126000 feet. It included several science experiments and temperature and radiation measurements were made. SHARP 3.1 followed in 2013 and reached 121000 feet. SHARP3.1 carried with it several experiments, Arduino microcontrollers and a small radio controlled aircraft.

Integrated Science, Technology, Engineering and Mathematics Education

I'm not sure that any of the teachers involved in SHARP were aware of integrated STEM (Science, Technology, Engineering and Mathematics) education back in 2009 and 2010. Like our students, we were learning and just having fun. The teachers were impressed that creative problem solving occurred naturally during SHARP noon hours. As teachers, we appreciated the freedom of not having to follow a prescribed curriculum or having to evaluate student work in terms of achieving specific learning outcomes. Each student brought with them unique skills and knowledge to be tapped. Older students naturally mentored the younger ones and acted as role models. Team work was essential for success. When something didn't work, it was usually because of poor communication between teams.

SHARP represented what we started calling "authentic learning". Every education student learns about Bloom's Taxonomy which refers to the classification of the different learning objectives. Bloom's Taxonomy divides educational objectives into three domains: cognitive, affective, and psychomotor. Good teachers employ all three domains in their lessons. In SHARP, the student is largely in control of their own learning and the student will naturally employ the three domains as they work their way through a problem.

Our highly motivated students worked very hard on their SHARP projects without the reward of a school credit but most didn't care. They saw the benefits. They learned how to solder, learned how to program microcontrollers, they become certified radio operators and they demonstrated that they could solve difficult problems often by trial and error and persistence. SHARP students needed to communicate their findings and teach each other thus reinforcing their learning. Some of them used these skills and their HAB experiments to win science fair awards. Learning was clearly evident even if no pencil and paper tests were written.

After each flight, the SHARP team sets new goals for the next HAB mission. High altitude balloon flights are a yearly activity with launches typically taking place in late October or early November from western Manitoba. The launch location is selected so that the payload lands on the floodplain south and west of Winnipeg. By the fall of 2013, SHARP had successfully flown three HABs. One mission was aborted (SHARP 3) due to extremely bad weather. Each mission has been more ambitious than its predecessor with more science experiments, better engineering, larger balloons, more advanced payloads and improved procedures.


Figure 3. The SHARP 3.1 radio controlled aircraft high above Manitoba.

Besides using amateur radio for tracking and communications during operations, SHARP students do radio direction finding activities to help in locating payloads on the ground. "Home-brew" directional antennas have been built. Certified students can borrow SHARP transceivers. However, they are strongly encouraged to buy their own Baofeng UV-5r[v] hand-held transceivers because their on-air skills progress much more rapidly when they have their own radio. Arduino microcontrollers are an important feature of the HAB payloads. SHARP students can take an occasional noon hour Arduino microcontroller class. Senior students are used as instructors. Students also practice their radio controlled aircraft flying skills behind the school and in the school gym when winter weather prevents flying outside.

Fundraising and promotion of the program is ongoing. We have been the beneficiaries of outreach programs but SHARP students also do outreach. Our students have made numerous presentations especially to elementary schools. They have been invited to several special events because of their amateur radio and aerospace activities. Whenever the students attend these events, valuable eyeball QSOs are made. Recently, SHARP received an Iridium satellite data transceiver after a student approached a Solara Remote Data Delivery representative while we were attending an aerospace trade fair. The transmitter even came with the offer of free technical support!

The Amateur Radio Community

SHARP has increasingly become involved with the local amateur radio community primarily through the Winnipeg Amateur Radio Club. WARC has supported SHARP in many ways. WARC and RAC (Radio Amateurs of Canada) are among our biggest donors too. SHARP teachers will strive to introduce more of our students to WARC and its many activities as well as the Manitoba Repeater Society and Winnipeg ARES. Engineering students of UMARS (University of Manitoba Amateur Radio Society) track our HAB flights using their satellite tracking station (VE4UM) and their APRS i-gate. Some UMARS students are SHARP alumni and some UMARS members have come to the school to deliver Arduino microcontroller lessons as part of their outreach program. There have been at least two dozen local hams that have made contributions to SHARP over the years.

Figure 4. The Shaftesbury amateur radio team, September 2014.

AMSAT and the Shaftesbury ARISS Telebridge Service

During the spring of 2013 we received a call from Alan Thoren to tell us that a friend of his would like to meet our team and possibly mentor our students. Stefan Wagener (VE4SW), a long time AMSAT member and the current Canadian ARISS delegate, came to the school during a lunch hour one sunny day in May. The students were outside testing a GPS controlled payload release circuit hanging below a small balloon. Stefan introduced himself and chatted with us for a while. He then visited the SHARP workshop and ham shack. Later he proposed the idea of building an ARISS telebridge station at the school. Of course we did not know anything about ARISS or what a telebridge was. Stefan patiently worked with us and it wasn't long before we were very excited by the possibility of our student hams facilitating astronaut contacts with schools around the world[vi].

A steering committee[vii] was assembled to guide the ARISS telebridge project. The committee included Mr. Stan Wiebe, the school principal. The project came to be known as SATS for Shaftesbury ARISS Telebridge Service. A budget was put together and a fund raising campaign started in the summer of 2013. A station call sign (VE4ISS) and a web domain name (ve4iss.ca) were obtained[viii]. A list of equipment[ix] was put together by Stefan and an overall plan for the classroom/satellite tracking station took shape. Soon we were stripping the interior of the old SHARP workshop. The floor was fixed and the interior was painted. New workstations were built and installed. The team assembled two 20 foot long directional antennas and the HamTV dish antenna during the long winter of 2013-14. Spring came late, but by May 2014 the antenna systems were in place on the roof of the school. Finally, two Kenwood TS-2000 transceivers were donated by Prairie Mobile Communications (Winnipeg) and Kenwood Canada. The antennas were connected to what we now call the SATS ground station by the end of June.

Figure 5. Assembling the HamTV antenna.

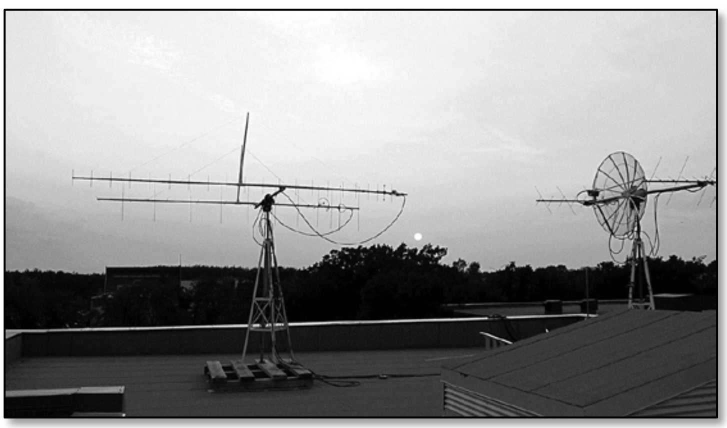

Figure 6. The ARISS telebridge ISS tracking antennas on the school roof.

The authors were really in over their heads on this project. Stefan exhibited considerable patience with our mistakes and the slow pace of progress. Snow on the roof was an issue into April this year. There was necessarily some bureaucratic red tape in dealing with the larger entity of the school division especially with respect to workplace safety, purchasing and information technology. One of the antenna rotors was giving us trouble requiring its removal from the roof on two occasions. That rotator has now been replaced. The twenty foot long, 2-metre antenna will oscillate slightly in the wind. We have had to do several realignments and tightening of brackets because of strong winds just in the first few months. Torque specifications for antenna mounting bolts still need to be worked out to stop movement and to prevent damage to the fiberglass boom supporting the antennas. As of September 2014, construction of the Shaftesbury ARISS Telebridge station is complete. The teachers and students still need to be brought up to speed on the station's operation but we expect that soon we will be ready for work and hopefully approved for ARISS contacts.

Secondary School Space Science Curricula

Mainstream science curricula across North America will likely include such topics as space exploration in the middle grades and universal gravitation, uniform circular motion and Kepler's Laws in physics programs. In the astronomy and space exploration unit[x], our grade 9 (senior 1) students make cardboard astrolabes. When used with a compass, they can measure the elevation and azimuth of celestial objects[xi]. The North Star will always be found at an altitude of 50 degrees in Winnipeg (our latitude). The position of the other stars varies according to the time of day. Many hams will use a similar method to determine the elevation of their hand held directional antennas when working satellites. We look forward to seeing our students attempt to work satellites with their home-brew directional antennas.

An advantage of working with a satellite, as opposed to measuring the position of a star, is that it can be done at school during the day regardless of cloud cover. A notebook computer running SatPC32 or similar software would be a big help in predicting the satellite's pass and important for the teacher planning the lesson. An extension activity could involve the use of a satellite tracking system such as the WRAPS[xii] or similar rotator system. By attaching a green laser pointer to a WRAPS rotor or satellite rotor simulator[xiii] it should be possible to mark the passing satellite in the night sky, aiding students in pointing their directional antennas. Stellarium[xiv] is a free planetarium program that can be used to point a telescope much like SatPC32 is used to point an antenna. Stellarium might be used with a WRAPS or rotor simulator to mark a star with a laser or point a small scope[xv] or camera. A rotator like WRAPS that helps in viewing celestial objects as well as working satellites could increase its acceptance by astronomy teachers.

Universal gravitation is a topic studied by our grade 11 physics students. When combined with the topic of uniform circular motion in grade 12, Kepler's Laws are confirmed. Only circular orbits are considered mathematically. The table below shows the space related learning outcomes in the Manitoba Physics Curriculum for the grade 12 (senior 4)[xvi]. Other North American physics curricula would be similar.

TOPIC 2.1: EXPLORATION OF SPACE
S4P-2-1 Identify and analyze issues pertaining to space exploration. Examples: scale of the universe, technological advancement, promotion of global co-operation, social and economic benefits, and allocation of resources shifted away from other pursuits, possibility of disaster
S4P-2-2 Describe planetary motion using Kepler's three laws. Examples: relate Kepler's Third Law to objects other than planets, such as comets, satellites, and spacecraft
S4P-2-3 Outline Newton's Law of Universal Gravitation and solve problems using $F_g = \frac{GMm}{r^2}$
S4P-2-4 State the gravitational potential energy as the area under the force-separation curve and solve problems using $E = \frac{-GMm}{r}$
S4P-2-5 Solve problems for the escape velocity of a spacecraft. Include: Law of Conservation of Energy, binding energy
TOPIC 2.2: LOW EARTH ORBIT
S4P-2-6 Compare the Law of Universal Gravitation with the weight (mg) of an object at various distances from the surface of the Earth and describe the gravitational field as $g = \frac{GM}{r^2}$

S4P-2-7 Outline Newton's thought experiment regarding how an artificial satellite can be made to orbit the earth.
S4P-2-8 Use the Law of Universal Gravitation and circular motion to calculate the characteristics of the motion of a satellite. Include: orbital period, speed, altitude above a planetary surface, mass of the central body, and the location of geosynchronous satellites
S4P-2-12 Describe qualitatively some of the technological challenges to exploring deep space. *Examples: communication, flyby and the "slingshot" effect, Hohmann Transfer orbits (least-energy orbits)*

Learning outcome 2-8 above involves orbital properties such as speed, period and altitude which can be readily visualized with the help of software such as SatPC32. Few teachers would be aware of this tool unless a radio amateur who works satellites shows it to them. We use SatPC32 in the Shaftesbury ARISS telebridge station. Science teachers at Shaftesbury can take students into the ground station and show them satellite orbits on large computer monitors. Questions like "why are the orbits displaced westward with each pass" or "why is the footprint of one satellite bigger than another" naturally arise. The questions can be easily related to the rotation of the Earth and the satellite's altitude, speed and period. Students can use the satellite orbital parameters on the monitors to determine other parameters using their physics knowledge (e.g. Calculate the mass of the Earth from the radius of the ISS's orbit and its period). All students love computer games. Kerbal Space Program[xvii] (KSP) is a very popular space flight simulator which has even caught the eye of JPL software engineers[xviii]. We encourage Shaftesbury students from grades 9 to 12 to play KSP because of its realistic simulation of orbital mechanics.

A Perspective on STEM Education

The STEM model is based on the idea of engaging students in the four specific disciplines of science, technology, engineering and mathematics using an interdisciplinary and applied approach. The goal of STEM education is to integrate the four disciplines using real-world applications. Our experience with the SHARP and SATS projects shows that this model is very effective.

In Canada, provincial governments are responsible for setting curriculum standards. In Manitoba there is currently no provincial STEM education legislation and no provincial STEM curriculum (Manitoba Education, 2014). STEM education in Manitoba is only implemented locally by a small number of educators in the form of extra-curricular activities. Despite this, enrolment in the Faculty of Engineering at the University of Manitoba— Manitoba's only engineering faculty—continues to climb. In the fall of 2012, enrolment in the faculty increased by 15% (Danakas). In the United States, STEM education is a national priority according to the May 2013 report from the Committee on STEM Education National Science and Technology Council in their STEM Education 5-Year Strategic Action Plan (US Government, 2013). The need for educators to train our 21st century learners, so they may move beyond the age of information towards an era of innovation is great, in order to meet increasing global demands in STEM related fields. This is our goal as STEM teachers; to develop future scientists, technicians and engineers through programs like SHARP and SATS and to inspire other teachers to do the same.

To engage more teachers, the authors have begun to work with MAPT, the Manitoba Association of Physics Teachers. We want to collaborate. We hope to kick-start other HAB programs and demonstrate how amateur radio is used to work satellites with low cost technology. We have asked teachers and students from other schools to join us in amateur radio certification classes. Shaftesbury High School will be hosting the annual general meeting of the MAPT this fall. This event will include a tour of the Shaftesbury ARISS telebridge station. We hope we can make a lasting impression so we can build a STEM school support network where amateur radio is the key to an exciting Manitoba space education program.

We think it will take some time before we see mandated STEM curricula being delivered in most schools. There is movement to replace standard laboratory courses in the sciences with more discovery or inquiry based courses. This was the approach taken by the College Board in developing their new Advanced Placement[xix] courses in algebra physics. However, the key signs of mature STEM programming such as curriculum rollout and teacher training in-services are faint. This may not be such a bad thing for groups such as AMSAT that see amateur radio as having an important role to play in advancing space education. Amateur radio is starting from behind in terms of teacher recognition. Biotechnology, robotics and forensic science programs are popular and more established in schools and it seems, more likely to be included in future curricular STEM programs. Most teachers do not realize that space is accessible through amateur radio. In time, amateur radio may be recognised by educators and so make a significant contribution to space education in primary and secondary schools.

So, will there be a significant place for amateur radio in STEM education? That may depend on the effectiveness of groups like AMSAT and the ARRL. NSTA (National Science Teacher Association) conventions[xx] are good places to reach science educators. Science and technology teachers need to be made aware of the potential of amateur radio and convinced that the benefit to their programs is worth the considerable investment of their time. The hands-on support of the local ham community is important too. Teachers willing to give amateur radio a try will face the hurdle of certification and a new technology learning curve. They will need some support. Local amateur radio clubs can provide the support. The clubs should be encouraged to reach out to teachers and demonstrate the educational potential of amateur radio as it pertains to the high interest area of space exploration. By providing certification courses to students in schools, the clubs can build their membership. We applaud AMSAT, the ARRL and RAC for the leadership they are providing through teacher and student education programs including ARISS, FUNcube and the FOX project.

Shaftesbury ARISS Telebridge Station Equipment

ARISS Primary Antennas

	22-Element CP 2m Yagi Specs	**42-Element CP 70cm Yagi Specs**
Model	2MCP22	436CP42UG
Frequency Range	144 to 148 MHz	430 to 438 MHz
Gain	14.39 dBic	18.9 dBic
Front to Back	25 dB Typical	25 dB Typical
Elipticity	> 3 dB	1.5 dB Typical
Beam Width	38°	21° Circular
Feed Type	Folded Dipole	Folded Dipole
Feed Impedance	50 Ohms Unbalanced	50 Ohms Unbalanced
Max VSWR	1.4:1	1.5:1

ARISS Secondary Antennas	**Rotors/Cables**	**Radios & Additional Antennas**
• 2 Gulf Alfa Dual Band 2m/70cm satellite yagis (phased for 2m & 70cm) • RF HamDesign HamTV 1.5m dish (Kuehne LNB downconverter)	• RF HamDesign 1x Spid RAS HR, MD-01 controller • RF HamDesign 1x Spid Big RAS HR, MD-01 controller • All LMR400/600 cables to station	• Kenwood TS-2000 & TS-2000X (primary & secondary radios) • Kenwood TM-D710A Mobile • Yaesu FT-8100 • Diamond 2m/70cm vertical • 2m Tape Measure Yagi • 2x ICOM V80 Handheld • 2x Baofeng UV5R Handheld

Software		**TNC**
• SatPC32 • Nova for Windows • Orbitron	• UISS • DireWolf • FL-digi / FL-digi HAB	• 2 Signalink USB • 2 Kenwood PC-1A Phonepatch

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Endnotes

[i] Our teacher-librarian at this time was Michael Friesen. Mike is a space enthusiast. He now teaches at Fort Richmond Collegiate in Winnipeg.

[ii] Airborne amateur radio APRS is not lawful in the UK. However there is a great deal of HAB activity there including school activity. The UK High Altitude Society (UKHAS) employs a worldwide volunteer network of hams for tracking HABs that has served well.

[iii] SHARP still contributes students each summer to the University of Manitoba Space Camp.

iv SHARP 1 Mission Goals:

1. To launch a scientific research payload on a High Altitude weather Balloon (HAB)
2. To track the payload using the amateur radio APRS - Automatic Packet Reporting System
3. To recover the HAB and its video camcorder
4. To record images of the curvature of the Earth and of outer space
5. To obtain flight data including altitude, airspeed (wind velocity), latitude and longitude
6. To report the findings of the mission

[v] Baofeng UV-5r dual band HTs can be purchased in bulk for less than $40 each.

[vi] Students at Sacred Hearts Academy a K-12 school in Honolulu, Hawaii have operated an ARISS telebridge station since 2000 and supported SAREX before then.

[vii] The steering committee consisted of Stefan Wagener, Stan Wiebe (our very supportive principal at Shaftesbury High School), Derek Boutang (Pembina Trails School Division Director of Information Technology) as well as the authors.

[viii] Ve4iss.ca is reserved. We have not yet begun to develop this web site. Our current site address is http://shsballoonproject.pbworks.com . We have a Twitter presence at https://twitter.com/rjstriemer and photos are stored on flickr.

[ix] The hardware list included three computers (Windows 7 / SatPC32), six monitors, two wall mounted 50 inch monitors, two uninterruptable power supplies, two RF HamDesign rotors and M^2 Antenna Systems directional antennas and eight foot towers, pre-amplifiers and amplifiers (donated by the Winnipeg Amateur Radio Club) , Tigertronics TNCs, SignaLink soundcards, polarity switches, antenna switches and coax cable, grounding rods and a grounding bar. Two new Kenwood TS-2000 transceivers were very kindly donated by Prairie Mobile Communications (Winnipeg) and Kenwood Canada.

[x] http://www.edu.gov.mb.ca/k12/cur/science/outcomes/s1/topic_charts.pdf

[xi] S1-4-01 Use a coordinate system to locate visible celestial objects, and construct an astrolabe to determine the position of these objects. Include: altitude, azimuth.
S1-4-02 Observe the motion of visible celestial objects and organize collected data.
Examples: graph sunrise and sunset data, track the position of the Moon and planets over time.
S1-4-09 Explain how various technologies have extended our ability to explore and understand space.
Examples: robotics, Canadarm, Hubble telescope, Lunar Rover, space station, Sojourner Rover, Pathfinder and Galileo space probes...

[xii] http://ww2.amsat.org/xtra/wraps-mark-spencer-wa8sme-qst-jan-2014-copyright-arrl.pdf

[xiii] http://www.arrl.org/files/file/ETP/Antenna%20Rotor%20Simulator/Article.pdf

[xiv] http://en.wikipedia.org/wiki/Stellarium_(computer_program)

[xv] http://simonbox.info/index.php/astronomy

[xvi] http://www.edu.gov.mb.ca/k12/cur/science/found/physics40s/index.html

[xvii] http://en.wikipedia.org/wiki/Kerbal_Space_Program#Physics

[xviii] https://web.archive.org/web/20131227041757/http://www.penny-arcade.com/report/article/nasas-jet-propulsion-lab-is-obsessed-with-a-certain-game-and-i-bet-you-can-

[xix] http://apcentral.collegeboard.com/apc/public/courses/teachers_corner/224794.html

[xx] http://www.nsta.org/conferences/