## Innovation Project Presentation

**Simon**: Hmm, it's so cold in here. Can someone turn on the heater please!

**Bernice**: *shows temperature increases*

**Simon**: It feels much better now.

**Hannah**: In the meantime…

**Bernice** (TV):
*shows money gets burned*
*trees dying*

**Simon**: Shoot, why is my energy bill so high?!

**Danny**: you are heating up the entire house, Simon, even though you're the only one here?

**Simon**: Excuse me??? Isn't that my only option??????? :( I need to stay warm!

**Bernice** (TV):
BREAKING NEWS! There is an energy shortage crisis this winter! The government requests all residents to lower the thermostat settings in the house!

**Simon**: But it's gonna be so cold! What can I do? Solvers of X and Y, we NEED your help.

**Tate**: Alright! Let's do some research on the internet first!

Internet: Research (Logos): *Statistics Canada & International Energy Agency IEA*
**Tate**: Look here, according to these agencies, the buildings sector accounts for about a **quarter** of total final energy consumption.

**Caden**: Yeah, and *65%* of this energy consumption comes from heating and cooling! That's a LOT!!!

Books: *SuperPowered*
**Kevin**: Ryan, let's find solutions from the book. Look, it says here we can use solar panels and windmills to generate renewable energy. That can help!

**Ryan**: Yes, I agree. But do you still remember what Elon Musk would do before he starts solving any problem?

**Kevin**: First Principle thinking (*Elon with Frist principle photo)!

**Ryan**: Exactly! It we follow this path, shouldn't we try to reduce the energy consumption first?

**Kevin**: I think both approaches are good. But which one should we focus on?

**Ryan**: Oh, why don't we do a survey to ask our community for their opinions?
Survey (Pie chart):
**Hannah**: Judges, our survey shows people would like to reduce energy consumption.
**Danny**: How do we do that?
**Hannah**: I think we should ask some experts.

Experts:
**Caden**: Hi Professor HVAC! Our team is struggling to find something that can help us stay comfortable in our houses, without using a lot of energy. Do you have any suggestions?

**Sophie** (Professor HVAC): I know! Why don't you use a heat pump? It runs off electricity, not the natural gas, so it's cleaner and produces less greenhouse gas emissions. Compared to traditional HVAC systems, it can provide up to 300% efficiency. And it does both heating and cooling in one unit! You could get a mini heat pump, so you don't have to heat or cool your house as much. Then you can spot heat or cool the person. This way, you will lower your energy bill and also lower the CO2 emissions.

**Danny**: Okay, but how will we condition the person if they move around?

**Sophie** (HVAC): Oh, that's not my expertise… Try asking Professor Robot.

**Ryan** (Professor Robot): Solvers, think about the innovation project you did last year!
**Kevin**: Oh yeah! We made an AI vision assisted cargo robot. We can use that!
**Simon**: But hold on, is that robot powerful enough to carry a heat pump?
**Ryan**: Why don't you hack a hoverboard? It can carry heavy loads, like your heat pump! You can also use your Huskylens AI vision sensor to track the occupant.
**Caden**: BINGO! Let's work on it now :)

Hannah(drift in with Tesla logo): Fun fact, new Teslas models use heat pumps to condition their cabin!

Hannah: A few months later…

**Ryan**: Judges, may we present to you our *MACH*, the *Mobile Air Conditioning & Heating* robot. As you can see, our robot base is a modified hoverboard. A mini heat pump unit sits on it, which is powered by an environmental friendly LiFePO4 battery. We use 100 W solar panels to charge the battery.

After successfully hacking the motherboard of the hoverboard, we realized the hoverboard could not run at a steady low speed. Then we used the motor driver board to regulate the three-phase brushless motors, which significantly improves the accuracy.

**Tate**: We used a low-cost Arduino to make the controls. Additionally, we used an AI vision sensor called Huskylens to track the object so it can follow the occupant.

**Kevin**: To make it clearer, we made a circuitry diagram to show our control system.

**Sophie**: Judges, this diagram shows how heat pumps work as a refrigerant system. As you can see from here, it can do both heating and cooling.

**Hannah**: We've made two innovative improvements over the traditional heat pump. The traditional heat pump has to exchange heat between indoor and outdoor. Our heat pump exchanges the heat within the indoor environment only. The second innovation is on the heating and cooling switching mechanism. The traditional heat pump uses a reversing valve on the refrigeration system to make the switch. Because our heat pump is smaller, we do not have space for a reversing valve. We developed a four-way air-exchange mechanism to instantaneously switch the air between heating and cooling.

**Impact…**

**Kevin** In order to evaluate the benefits of our MACH robot to the energy savings as well as the GHG emission reduction, we conducted a whole house energy simulation using Hot-2000, a tool developed by Natural Resources Canada. We simulated a typical 2200 square foot detached house, located in York Region. Our baseline simulation shows that this house consumes about 2700 $m^3$ of natural gas prior to using our solution. And the natural gas consumption can be reduced by **16%** with our MACH system. In addition to the money savings, our solution can reduce about 0.4 metric tons of $CO_2$ emissions per year per house. With 16 million dwellings in use in Canada, our solution could help our country to cut down 1% of total GHG emissions.

**Bernice** (TV):

BREAKING NEWS! The situation has become less severe, with Solver X and Y's innovation! We can all go outside now!

Pans to Solvers X and Y cheering and being happy!

## Questions:

1. Why does your team choose the 1st tournament event to attend? (Are you ready yet?)
   **Answer:**
   Judges, to be honest, I don't think we are **100%** ready. Even until last night, we were still working together to fix some issues of our innovation project. But, we feel confident today to bring you our outcome. The other thing, as the senior team of our coach, we have committed to mentor 3 other junior teams, which will compete later. We need to plan out our time to help them, and that's why we are here today.

2. Can you talk about how you develop this innovation project? (similar question, how does your team work together, need slight modifications.)
   **Answer: (Hannah to point to the poster)**
   Just like before doing any project, we need to IDENTIFY the problems. We did various types of research, including the 1) FLL mat, 2) internet research, 3) reading books, 4) surveying, 5) site visit to a research facility and 6) talking to academic and industry experts, we realized that the building sector consumes 25% of total national energy, and 2/3 of that is due to the heating and cooling. Majority of the heating source is the natural gas, which is a big contributor to $CO_2$ and greenhouse gas emissions. As shown from the data, the building sector is one of the biggest GHG emission contributor. On the other hand, in Canada, electricity production is relatively clean (think about why?). So, we start to think, how can we lower energy usage as well as reduce GHG emissions?

We brainstormed all our ideas, and used the First Principle Thinking approach to identify the problem. We eventually chose the heat pump technology as our solution.

3. You talked about the First Principle Thinking, can you explain it a bit and how did you use it for your project?
   **Answer: (Ryan to point to the poster)**
   First principle thinking is a physics way of looking at the world. You boil things down to the most fundamental truths and then reason up form there. Specifically to our problem, we asked ourselves, what's the problem here with the heating and cooling? Do we want to heat the house or do we want to heat the person inside. The answer is clear, the person. Now, if we reason up from the person, we asked ourselves, can we just heat or cool the target person instead of the entire volume of the house? The answer is also clear, Yes. That's how we decided to use an electrically powered high-efficiency small-size heat pump as our solution.

4. It looks like a fairly advanced project and there are many challenges in this problem. You did very well. I'm wondering how did your team manage to get it done and did you get any help?
   **Answer:**
   Yes, we really learned a lot through this innovation project. As a big team of 9 members, we were able to separate the big challenge into multiple smaller task groups after brainstorming and researching together. We have groups doing heat pump, robot, simulation, as well as the presentation. And then we share our findings and knowledge with all members to make sure we can integrate our partial solutions together.

   We meet 6-8 hours a week, sometimes even more. We communicate and share information on Slack, which we found a very efficient tool. Some of our team members even give up their basketball and hockey time for our project.

   Just like any other project, we always run into both technical and mental challenges. We are blessed that many experts helped us, from refrigeration system to pipe design. We are very grateful that we have a wonderful coach who sacrificed a lot of his time mentoring us and connecting us with the right experts. Our coach not only teaches us technical knowledge, but also inspired and encouraged us along with this FLL journey.

5. Can you explain why you choose heat pump?
   **Answer: (Hannah to point to the poster)**
   Advantages of heat pump:
   1. Using clean electricity as the fuel to lower GHG emissions.
   2. Can do both heating and cooling.
   3. Higher efficiency, COP of 3.0 or more.
   4. It has a huge market size, according to analysis, especially with the COP26 target.
   5. Tesla uses it.
   6. Natural gas prices very high now, so economically it's better to use electricity.

6. How do you choose THIS heat pump?
   **Answer: (Hannah to point to the First Principle Thinking)**

That's a great question, and we did spend a lot of time before getting this heat pump unit. We followed the First Principle Thinking approach and identified we need a small heat pump that uses less energy to heat or cool a person only. But how do we select the right size? The dimensions are for sure important because we need to fit it onto our robot. But more importantly, it's the CAPACITY. According to the ASHRAE (American Society of Heating, Refrigeration, Air Conditioning Engineering) Standard, to condition an average adult, it needs about 120 W of energy. Based on this number, we found a manufacturer called RIGID HVAC who makes mini heat pumps like this. The compressor is very small, just like the size of a coke. But it can provide up to 450 W of cooling and 600 W of heat, with a high COP of 3.0. That's how we chose this one as our heat pump.

7. What makes you develop your air delivery system (all the pipes, air-directions etc)?
   **Answer: (Hannah to point to the Heat Pump PVC pipes)**
   This is a very interesting one. Actually, we are "forced" to develop this air delivery system, based on our need. When we learn heat pump in theory, we know the heat pump can do both heating and cooling, and it was invented for heating at the first place. However, to our surprise, when we discussed with the manufacturer's engineer, we learned that this mini heat pump can only do cooling, because the compressor is so small that the refrigerant can not be pushed through the system for heating purposes. They tested it before with their mini reversing valve but no good results. So, in order to make it work, we are "forced" to develop this reversing mechanism, not from the refrigeration side, but on the outside air delivery side. As you can see from these pipes…

8. How did you use/learn the simulation software? How do you make sure the data is correct?
   **Answer: (Hannah to point to the poster)**
   Learning HOT2000 the simulation software is another whole new level. We realized that there are so many things we need to learn. Luckily, our coach has some expertise in energy management and connect us with Professor Fung from Ryerson University. He walked through us with the simulation.
   For the results, our coach asked us to always double check and triple check with references. He said, "garbage in, garbage out". So, after we finished our simulation, we looked at the National Gas Association report. For example, our house baseline consumes about 2700 m$^3$ natural gas, with a 2200 sq.ft detach house in York Region. The national average consumption is about 2300 m$^3$. So, our number is very reasonable.

9. How did you choose to use Hoverboard?
   **Answer: (Hannah to point to the poster)**
   It's a continuation of last year's innovation project, where we developed a smart robot to help delivery agent to deliver the parcels in the last mile. This year, when we realized that we need a moving spot heating/cooling device, we right away though of our cargo robot. Based on our experience, we know our previous prototype doesn't have enough payload, so we did some research and found that many robot designers modified the retired Hoverboard because it can support up to 250 lb. We followed the online instructions and hacked the motherboard successfully. But we also found the control is a bit challenging, which requires knowledge of ROS (Robot Operation System). And the

speed control is not that great, especially at the low speed that we want. So, we improved our previous solution and came up with this current circuitry design.

10. I'm glad to see your last year's innovation project used by the big carrier companies. Do you mean they partner with your team and used your product?
    **Answer:**
    We just learned this great news last week that Canada Post and Purolator are testing their pilot project which is quite like our last year's solution. We don't know if they referred to our project idea or not because no one contacted us, but we are very happy to see our innovation adopted/used by our community.

11. Can you explain a bit how heat pump works?
    **Answer:**
    (I'm not providing here and everyone should know how to answer.)

12. Did you get any **feedback** on your project?
    **Answer:**
    Yes we did. We showed our prototype to researchers at the Archetype House. They were very excited to see this innovation, and told us our solution can be tied into their current Heat Pump research and is a very smart solution. They will help us with some improved calculations and promote our ideas to the government and industry partners.

13. What's your favourite part of this project?
    **Answer:**
    Examples:
    1. Hacking the motherboard, shortening the circuit and fixed it.
    2. Able to use our previous knowledge and continue improving our robot design.
    3. Learned how the heat pump works and made the innovative solution to redirect the air flows using pipes and fittings. As a matter of fact, spending 2 hours in Home Depot and look for parts is fun.

14. Did you do this work all by yourself?
    **Answer:**
    We did most of the work by working together as a whole team, by doing research, assembling the robot and heat pump and coding. But there are many advanced topics we don't know yet at our age and level. We are blessed to have the opportunity to meet and talk to many field experts and learn their experiences. We incorporate many of their advice into our project design. Our coach, also gave us tremendous help and mentoring. He can always find ways helping us get the project done.

15.

Justification:
Most of the electricity production in Canada is relatively clean. Building sectors account for a quarter of energy consumption, which is pretty significant. In Canada, the natural gas demand is a lot more than ones of electricity, and building sectors produces a lot of GHG emissions. Because electricity is cleaner than natural gas, who is a big contributor to Co2 emissions, if we can find a technology that can reduce natural gas usage and increase

electricity usage, it will be able to cut down Co2 emissions significantly.Why this heat pump:
We did some research and realized that an average person needs around 105 watts of heat when at rest. Our heat pump generates 600 watts of heat for 150 watts of electricity, which is enough for an average person. Along with that, this heat pump is compact enough to fit on our hoverboard. This is why we chose this heat pump.Why Huskylens:
Well we did our research, husky lenses aren't too expensive. Huskylenses are also simpler to use in terms of programming and is the usage is within our knowledge, yet it is still effective enough, which makes it a good choice for our team.Improve:
Regulate heat pump capacity
Huskylens to Open CV
Automated valveIntegration:
Technical skills to integrate, wether its attachments we develop or attachments that inspire us. We didn't invent a heat pump, nor did we invent the heat pump. However, putting both together is something that hasn't been done before, and something that we did. But beyond being technical, we, as a team, are also integrating our knowledge to help others. Our coach has three other younger teams. We are always thinking of being inclusive and diverse in the STEM community, so we integrate our knowledge into the learning of the younger teams. We try to inspire them so they can, and would want to be in a STEM community. So this is why we identify as integrators, not just as individuals, but as a team and a community.Implementation:
Show case product to communities.
Feed back
Crowdfunding project(kickstarter) to test the water and see who's interested.
We ant to try to use as much recycled product as possible we, including parts of our innovation like the hoverboards.How does Huskylens work:
Our heat pump does spot heating and cooling. But one thing to realize is that the person that it's heating or cooling can move around. We decided to still do some research and were able to narrow our choices down to two: LiDAR and vision sensors. We realized that LiDAR will not ba able to tell the difference between two objects, and we need our sensor to be able to tell who is what is where. In terms of the vision sensor, we choose to use huskylenses because it is simple enough to program and isn't as expensive. We are thinking to switching it to Open CV when we feel ready to code that. (edited)

**Robot Design Presentation**

**Kevin:** Judges, we developed our robot based on three design principles: Reliability, repeatability, and stability, with the emphasis on error handling strategies.

We use both hardware and software solutions to achieve the goals.

Hardware:

- Core: **Bernice** We went through multiple design iterations and came to this final compact design. We added extra pins and connectors to improve the robot's structural integrity.

- Forklift dumper: **Hannah** We developed a unique, and innovative attachment inspired by the forklift and dumper idea. It is driven by a large motor through the parallelogram linkage mechanism. Our innovative solution is to connect the Wind Turbine and the Toy Factory missions in the same run. As you can see, the robot collects the energy cells from the wind turbine when the arm is low. And the cells can be released to the Toy factory when the dumper tilt around the pivot point when the motor lifts it up to the desired height. This makes our attachment both a passive and an active attachment. We also used this attachment to multitask many other missions.

- Funnel: **Danny** One of the key things we want to address for our robot, is the error handling ability. We realized, and also found reports from many other teams, that no matter how many advanced coding strategies you use, there will always be some marginal errors, which could cause the mission fail. To compensate for that, we made a funnel to align the robot with the mission model to improve the accurate positioning of the robot.

- Software:
  - PID: **Simon** One of the coding strategies we used extensively in our missions is the Gyro-PID. We use gyro-PID strategy to ensure the robot running in straight lines. We also combined PID with speed change, acceleration, and deceleration, to prevent drifting and ensure the stability of the robot.

    - Color sensors: **Sophie** There are two color sensors in the front area of our robot. Through our testing, we learned that the motor rotation error will build up proportionally to the traveled distance. So, we use the centre color sensor to detect a line and then obtain new references to reduce the proportional errors.

    - **Ryan** During our testing, we found that even with the PID and line detection strategies, our robot may not position itself to the landmark repeatably, especially for our Run 1, where our robot has to clear 8 missions within one and a half minutes. So, we made an advanced line squaring strategy, by using two color sensors in the offset position to further improve the robot position accuracy.

  - **Tate** In addition to improving the accuracy of robot positioning, we also use the Stall detection strategy to recalibrate the starting position of the attachment. For example, this main arm is very critical to many missions, so it has to position to the desired height repetitively to improve the reliability.

- **Caden** As a team inspired by FLL, we want to give our knowledge and experience back to the community. One thing we found is that many younger teams got frustrated during the robot testing because of the lack of experience and mathematic skills. To help them and ourselves, we developed a program called Path Planner to simulate the mission testing. The Path Planner will tell you the approximate distance that the robot needs to travel and the angle to be turned to with a few clicks of the mouse. We tested this program on our robot as well as three other junior teams' robots, and we saw clear evidence of testing time savings as well the improvement in younger kids' engagement.

Mission Planning

- **Bernice** For the robot missions, we have 4 runs in total. The first run is the most critical one since it takes about 1 minute and 30 seconds to finish and needs to clear 8 missions in the North and Central areas (Show a path map). As a matter of fact, we spent most of our time testing this run to ensure a good successful rate. This kind of feedback from our testing helps us improve the robot design in both hardware and software.
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- **Danny** For example, for the original design, our robot has two medium motors to drive the attachment. After two months of testing, we realized some major stability issues, so we replaced one medium motor with a large motor, and then retested the missions. The Advanced Line Squaring is also the outcome of this type of feedback-testing process.
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Conclusion

**Danny** Judges, this is the conclusion of our robot design presentation, and we are delighted to answer your questions now.

You said you used PID a lot; what is it?

- It is an error feedback algorithm that helps the robot go straight. P is proportional, is the current error. It is integral, is the sum of the historical errors. D is derivative, is the future errors we might make. We combine all of these errors to help our robot move straight reliably.
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So what's the coefficient of the PID?

- Our coefficient for Proportional is 0.6. We found this by isolating the P because the P is the most important and relevant error. We did trial and error and observed the performance of our robot. We started with one and slowly changed the number higher or lower to find out the best coefficient. In the end, we found that 0.6 works well as it oscillates nicley. Then we moved onto our integral coefficient. The integral coefficient is 0.0014. Because integral adds all the historical errors together, it will be too large of an error to be represented in the code. Because of that, we had to scale it down significantly so that it could be represented in our code. Our derivative is set at 0 because it is hard to predict and sometimes causes even more error than how it started out. However, we acknowledge that no matter how good our PID is it will still have errors. This is why we made the funnel.

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You talked about your advanced line squaring method. What is that?

- Line squaring: Unlike the traditional line squaring method, which uses two color sensors that are along the same line each other, we used two color sensors that are offset for our advanced line squaring. For example, our robot uses the gyro assisted PID when running. There can be errors in that, so we also use a line follower done by the color sensor to make our robot more accurate. We use the center color sensor to follow the edge of the line. We move until the other color sensor detects the edge of the T. This way we can more accurately position our robot than the traditional line squaring. The problem with traditional line squaring is that they can stop at any point along a line and still be perpendicular to it. With ours, it will be perpendicular and still be at the same point every time, making our robot more repeatable.