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# MAKER: Hands-On Engineering Scavenger Hunt, a CNC Clue Challenge

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Kim Gould graduated from the University of Calgary Schulich School of Engineering in 2011 with a B.Sc. in Civil Engineering, specializing in Energy and the Environment. She is currently working on building construction and renovation projects at Pivotal Projects, where she works as an Associate Project Manager. Kim was heavily engaged in extracurricular activities during her time as an undergraduate student. She feels that her involvement in the Civil Engineering Undergraduate Society and the Solar Decathlon "Spo'pi" project greatly enhanced her overall educational experience, and she strongly encourages current students to take advantage of similar hands-on activities in their time at school.

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## Introduction

In January each year, to celebrate the new semester at the University of Calgary, engineering students get together for a week of activities, competitions, and shenanigans. Homerooms, classrooms, and corridors bustle as departments participate in activities ranging from parades to movie nights to snow sculpture competitions. An activity unique to this week is called Key Clue – a week-long scavenger hunt to find a hidden key somewhere within the Calgary city limits. Viewed from an outside perspective, Key Clue could be compared to attempting to find a needle in a haystack, in a field of haystacks. Each engineering department forms a team that works together solving clues to find the key before the other departments. University alumni, in groups of two or three, organize and run the event, and are known as the Key Masters.

## Elements of Key Clue

Successfully creating a Key Clue event that is both engaging and challenging for students requires consideration of a few key elements. Each of these elements must to be properly balanced for the best result.

***Theme.*** Driving the momentum of the event throughout the week, the theme is what provides the team with a reason to be searching the city for a key, and it is essential to creating a successful Key Clue. Alongside the theme is a storyline that guides the teams through the week. Past themes / storylines have included a pirate seeking a lost treasure, a murder investigation that involved a missing key and a film noir-style private-eye searching for a lost object. Student teams must not only solve the difficult ciphers, but also understand their meaning within the context of the story.

***Final Solve.*** Every clue and activity throughout the six day event culminates in leading the teams to a very specific location within the Calgary city limits. Ultimately, the final solve must include:

1. *Deliberate culmination of all the week's clues:* Organizing all of the clues, ciphers, activities and items collected and solved throughout the week, and bringing every one of these together in order to achieve the final solve. No team should be able to "skip ahead" to the key's location without having solved the majority of the week's clues.
2. *Yield a relatively specific location:* Most typically, the teams should need to search an area that is no greater than 100m x 100m to find the key.
3. *Timely reveal of location information:* Halfway through the week, teams must not be able to approximate the key's location to a reasonably small search area. Employing the final clue must help to pull all prior information from the week together.

**Types of Clues**

Years of Key Clues organized by different individuals have encompassed such a wide variety of codes and ciphers that entire papers could be written to describe them all in detail – in lieu of this, a broad sampling is summarized below in Table 1:

Table 1. Summary of clue types with examples from past key clues.

| **Types of Clues** | **Examples from Past Key Clues** |
|---|---|
| Popular Cryptography Methods | -Hidden messages / steganography (invisible ink, image encoded in video)<br>-Traditional substitution ciphers (Caesar shift, pigpen, Vigenere, etc.)<br>-Traditional transposition ciphers (Caesar box, rail fence, scytale, etc.) |
| Physical Clues | -Pigpen cipher written on a scrambled Rubik's cube<br>-Wooden cube puzzle that reassembles into pyramid shape<br>-Wax candle with coded message embedded inside |
| Engineering Problems | -Wiring / circuitry analysis / logic gate problems<br>-Force balance analysis to solve projectile motion problems<br>-Route mapping using video of suspended weight in vehicle to gauge acceleration |
| Activities | -Events at archery / shooting ranges<br>-Lock picking to obtain a clue from a secured room<br>-Scuba diving to obtain a clue from the bottom of a pool |
| DYI Ciphers | -Instrumental sheet music written so notes correspond to Braille characters<br>-Origami-style folding a sheet of paper to reveal a QR code<br>-Rubik's cube scrambling instructions hidden in a navigational log<br>-Game of Sudoku adapted to contain a message |

A physical cipher that will be used in the 2016 Key Clue event will be outlined in this Maker project. Recognizing that the clue outlined here will be used in the 2016 Key Clue event, there will be a certain level of mystery contained within the published paper. Essentially, the paper will be written to allow the reader to understand how the clue is made. Were students participating in the event to happen upon this paper, they may find hints to help them uncover a solution and perhaps additional important information.

A typical Key Clue event contains 15-20 ciphers that need to be solved by the participating teams. The CNC clue outlined here will be one of those clues for Key Clue 2016. Critical information enciphered in this clue will help lead teams toward the hidden key that is their ultimate objective. However, at this time, the theme and story for 2016 remain undetermined, so the specific information contained within the CNC clue is unknown. Instead, this paper (and poster) will focus on the construction and implementation of the CNC clue.

## CNC Machining and G-Code

Now more than half a century ago, in 1952 the first Computer Numeric Controlled (CNC) machine was developed when researchers at MIT connected an early computer to a milling machine[1]. Going forward, the development of the CNC machine changed the capabilities of manufacturing by allowing for precise control, which provided increased reliability and accuracy, as well as product repeatability.

More recently, the Standards for Technology Literacy adopted by the International Technology Education Association[2] have stated that hands-on learning opportunities should be incorporated into the engineering curriculum. Emphasizing this is a rich body of literature based on multiple educational movements that has shown hands-on activities promote deeper learning and understanding of concepts[3].

Leading students toward a hands-on opportunity to work with a CNC machine will allow them to gain practical knowledge and be introduced to the various techniques of automated control, outside the typical classroom environment[4]. Operating a CNC machine requires that students understand the clearly defined procedure for the machine; typically this procedure is written using G-code. Operator errors, errors in the G-code, or incorrect execution of the g-code may cause mistakes in the final product, damaged tools, or damaged machines[4].

## CNC Clue

Key Clue 2016 will incorporate a CNC clue, which will use a simplified form of visual cryptography[5]. As a method that allows visual information to be encrypted so that decoding is a physical process, rather than a digital one, this is well-suited to a Maker project. The encoding is accomplished by dividing a written message into multiple parts, where each component is unreadable, but the original message is revealed when all of the components are overlaid (an example of this process is illustrated in Figure 1).

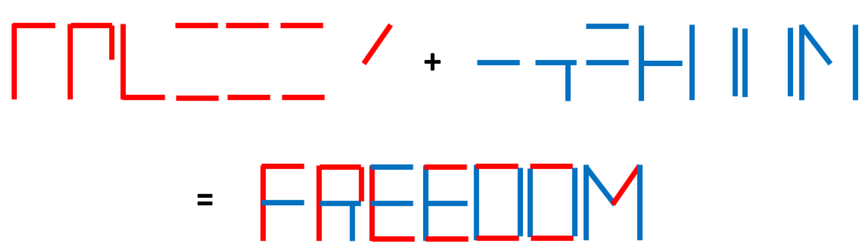


Figure 1. (top left) First message component
(top right) Second message component
(bottom) Overlaid components which provide the plaintext message

Typically, this process would be achieved by overlaying physical layers on transparency film or translucent paper, or by digitally compositing layers in image-editing software. However, for a CNC clue, the two message components would be provided in two different formats. Each team would first be provided with a physical, CNC-machined sheet of metal. Subsequently, each team would be directed to the G-code required to machine the second half of the message. In Figure 1, the teams would receive the top left image as a CNC-machined piece of metal, and they would receive the information for the top right image in G-code.

Locating the appropriate common origin point, and defining the correct orientation prior to G-code machining would be very important for teams intending to overlay the message components directly. Very likely in practice, the teams would machine a second metal blank of similar size to avoid destroying the original clue. Employing both completed metal plates as stencils, teams could manually overlay the information to determine the plaintext message.

## Goals for Student Engagement and Learning

Running a Key Clue is a very rewarding process. Watching students who participate in Key Clue become entranced and engaged in the six-day event and gain a wide range of skills is one of the most exciting aspects. A CNC clue will provide the students with the hands-on opportunity to develop their spatial abilities, creativity and abstract thinking.

Learning to use a CNC machine will require that students actively engage in understanding how integrating multiple areas of engineering can work together to produce a physical object[6]. Logistically, by dividing the message into two components, a physical CNC machined plate and G-code, the students will be required to integrate mechanical systems, electrical systems, and product-making together to produce the final result, a physical object that they can touch, feel, and inspect.

When compared to hands-off activities, research has shown that hands-on learning activities provide not only enhanced learning outcomes, but they also increase students' interest and motivation to learn[3]. However, computer-based programming (such as G-code) is not perceived by students to be hands-on learning, but rather hands-off learning[3]. Ensuring that computer-based technologies include a connection to the physical world is therefore very important. Requiring the students to combine the computer-based G-code with a physical object, in the context of this clue, achieves this aim.

Encouraging participation in Key Clue, and specifically the CNC clue, will also help the students to develop their innovation abilities. Supporting this, a recent paper writes that "creative and spatial abilities are allies in innovation: an innovator must visualize what does not yet exist"[7]. The paper goes on to further specify that "creativity is added when such artistic task demands are open-ended or require unique solutions, and spatial challenge is added when the tasks are demanding of visual manipulations"[7]. As described, the CNC clue will provide the students with both the spatial and creative practice. Navigating the clue to its solution is an open ended process which will require creativity, and the participants will need to spatially visualize the two components of the clue fitting together to create a plaintext message.

Development of this CNC clue has been done such that students are provided with an opportunity to step outside the box and consider different alternatives. Students will develop a systems approach to problem solving, and enhance their abstract thinking ability as a result of this active learning process[6]. Abstract thinking ability of Key Clue participants has improved so much in past years that, as the week progresses, the participants start suggest quite creative (and often comical) solves to the puzzles.

## Conclusion

Maker projects, where students are introduced to making their own physical creations, provide many opportunities to enhance student learning. Engineering students in particular are often given technical knowledge in their classes, but they may have little opportunity to apply this knowledge in hands-on activities. Employing the CNC clue described here will allow students to participate in hands-on activities that will develop their spatial abilities, creativity and analytical thinking. This clue will allow participants to develop skills in a unique approach that they otherwise would not have had the opportunity to do.

## References


[1] R. Martin, N. Bowden, and C. Merrill, "3D Printing in Technology and Engineering Education," Technology and Engineering Teacher, pp. 30-35, May 2014.

[2] International Technology Education Association, "Standards for Technological Literacy: Content for the Study of Technology," 3rd ed., 2007. [Online]. Available: http://www.iteea.org/TAA/PDFs/xstnd.pdf. [Accessed: 01-Apr-2015].

[3] D. Sianez, M. Fugere, and C. Lennon, "Technology and Engineering Education Students' Perceptions of Hands-On and Hands-Off Activities," Research in Science & Technological Education, vol. 28, no. 3, pp. 291-299, Nov. 2010.

[4] M. Milojkovic, M. Milovanovic, D. Mitic, S. Peric, M. Spasic, and S. Nikolic, "Laboratory CNC Machine for Education of Students on Control Systems Engineering," Facta Universitatis, vol. 13, no. 2, pp. 117-125, 2014.

[5] D. Rijmenants, "Visual Cryptography," 2014. [Online]. Available: http://users.telenet.be/d.rijmenants/en/visualcrypto.htm. [Accessed: 01-Apr-2015].

[6] R. Bruce, and S. Reiser, "Take Chances, Make Mistakes, Get Dirty," in IEEE SoutheastCon, 2010, pp.181-184.

[7] S. Coxon, "Innovative Allies: Spatial and Creative Abilities," Gifted Child Today, vol. 35, no. 4, pp. 277-284, 2012.