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Phillip du Plessix, University of Calgary

Graham Armitage, University of Calgary

Kara Chomistek, University of Calgary

Clifton Johnston, University of Calgary

Daryl Caswell, University of Calgary

Mohamed Nazir, University of Calgary

Marjan Eggermont, University of Calgary

Diane Douglas, University of Calgary

Brigit Knecht, University of Calgary

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Introduction

A tool and safety training program has been developed and implemented at the University of Calgary, Schulich School of Engineering for the first year design and communication courses. These courses promote a hands-on, inquiry based learning environment where students build and test a variety of projects in a dynamic, open-ended curriculum. To allow for a truly hands-on design experience, the laboratories are equipped with tool chests containing various hand and power tools, available for student use during the construction and testing of their projects. Despite the fact that there have been few injuries in the design laboratories, it became clear through observations of students and instructors that many of the tools were being used incorrectly. Allowing for student use of hand tools in the laboratory comes with inherent safety hazards and a need for some form of training. Tool training was not previously available in the laboratories, and students would have to seek out personal instruction if they wished to learn proper technique and operation of a tool. From both an educational and a liability point of view, safe tool use has become a priority. This paper will examine the role of tools in engineering education, review relevant writings on the topic, outline the methodology developed for the University of Calgary's first year engineering design course, and evaluate the impact of the implementation on the students. As one reviewer noted, "It saddens me to think that universities are teaching these basic skills that, in previous generations, were covered in grades 6-9."

The Role of Tools In Teaching

Since the mid 1990's, there has been significant pressure applied to engineering educators by accreditation boards to re-vitalize the real-world, open-ended, hands-on nature of engineering[1]. Undergraduate engineers are now being taught to design for the man-made environments in which they live – environments which widely require tools to be manipulated. Can we expect students to understand the process of hands-on design if they cannot engage in it? Although the first year design and communication course at the Schulich School of Engineering is not a technical based course, it is one of the few opportunities students have to become exposed to basic hand tools during their undergraduate academic careers. As stated by Gaba, "The goal of education is typically to teach or improve conceptual understanding or to introduce individual skills. For training, the goal is to implement or improve specific skills and behaviors needed to accomplish a real world job" [2]. Although technical skills are not a focus of this course, becoming familiar with as many aspects of design engineering as possible is, and knowledge about basic tools is relevant to a very large number of engineering applications. These applications include tolerancing, dimensioning, and familiarity with surface finish, material removal rates, manufacturing costs, interfacing theory and safety implications of designed products. Most engineering students enter into their first year with very limited knowledge of how to use basic hand tools, and are graduating in the same manner. A survey conducted on a sample of first year engineers attending the University of Calgary revealed that approximately 17% of students enter into their undergraduate with absolutely no previous basic hand tool training. As part of an engineer’s education, it is important that they are at least familiar with the functions and capabilities of basic hand tools.

It has been found that in order for adult education and training to be most effective, “training must be interactive and experiential”[3]. The element of practice is a key component of effective training, as the act of doing can teach a student much that simply hearing and seeing cannot[4]. As stated by Read and Kleiner, “The essence of learning theory can be summed up by the motto of Eagle’s Flight, an Ontario-based company that produces training games: “What people hear they forget, what people see they remember, what people do they understand”” [5].

Safety Implications

Along with the mission of providing students with a fully hands-on environment comes safety and liability issues regarding the potential for injury caused by the tools. If we are to make available to our students the tools they require for learning, we must not only train them in how to operate the tools properly, but safely as well. Fortunately, these two characteristics overlap far more often than not, as operating a tool safely also means operating a tool properly[6]. As long as students will have access to the hand tools in the design laboratories, the potential for accidents can never be completely eliminated. There are, however, measures that can be taken to prevent and reduce the likelihood of accidents.

As noted by Heath, “There are three ways of preventing accidents. Firstly, to make the working environment as safe as possible so that fewer dangers arise; secondly, to protect the worker from the remaining hazards by means of suitable protective clothing and equipment; and thirdly, to train him to act in a safe way at all times. The training of the worker to act safely is fundamental to the success of the first two” [7]. This template can be transferred to the laboratory environment, where the students can be considered employees. The design laboratories are in and of themselves safe areas, with no prominent dangers. The proper safety equipment is available to the students, and it is enforced that they utilize it whenever working with the tools. As Heath suggests, these precautions mean nothing if a tool is being used improperly or unsafely[7]. This can only be affected by giving knowledge to the individuals who will be operating the tools: the students. It has been emphasized for over twenty-five years that “training remains the fundamental method for effecting self-protection against workplace hazards” [8].

Teaching students about the safety issues associated with designed projects is also an important part of practicing responsible engineering. After implementing and assessing a health and safety training program at the Université de Sherbrooke, the following was noted: “Whether for the design of new machines or for the modification of existing machines, the engineer has to make decisions that will have a major impact on the health and safety of workers. It is thus essential that the engineer be able to adequately assess risks” [9]. For these reasons, providing safety training for students will not only reduce the likelihood of accidents, but will give students an opportunity to learn about the importance of safety considerations in the design process.

History of Tools at the University of Calgary

When the design course was first run in 2002, there were no requirements for the students to use the tools, and minimal training was available for the students to learn how to properly operate them. During the winter semester of 2006, the Schulich School of Engineering requested that some form of tool training be developed and implemented before students could acquire access to the tools. A competency based requirement was immediately developed and implemented. The requirement involved a student reading a short document outlining the uses and operation of a specific tool, and demonstrating safe handling and operation of the tool to his/her laboratory instructor. At this point the student may be deemed competent and would be permitted to use the respective tool during construction laboratory times. The documents were prepared by one of the teaching assistants of the laboratory and posted online for student access. These documents would have to be obtained and supplied by an interested student, and a demonstration time would have to be scheduled with his/her laboratory coach.

The existing method of tool training was ineffective in that it only exposed a small number of students to the tools in the toolboxes. Only a student requiring the use of a specific tool would gain knowledge about the proper use and operation of that tool. As well, the knowledge gained would be unique to that tool. This is unsatisfactory, as one of the goals of a tool training program is to expose all of the students to a variety of hand and power tools, in order to increase their familiarity with the process of construction. An ideal tool training program for this course would include a method of exposing all students to a number of tools, yet (because of the non-technical focus) not require every student to competently operate all of them.

This method of training was also incomplete in that the student would be expected to demonstrate proper technique with a tool after only having read a short document. For many students, it is extremely difficult to learn physical skills from descriptions alone. Some individuals are able to learn effectively through description, while others learn best from explanation or demonstration[4]. With the existing setup, an explanation or demonstration was not reliably available; some of the coaches who would oversee the competency test would be no more familiar with the tools than the student. This scenario not only appears in our laboratories, but in a large number of other venues, including primary school where “Skills teaching is erratic and not always correctly done. Quite often the teacher is not confident or has not received adequate training in tool handling and therefore is not aware of the correct procedure”[10]. The need is for a tool training program incorporating visual as well as auditory explanation and demonstration that is equally accessible by all students prior to student practice.

The tool training program also fell short in that it was ineffective in training large numbers of students. The only method of keeping track of completed competencies was for the student to keep a copy of each of the respective documents for the tools his/her coach had signed off on. Coaches would be required to view the respective document each time a student wished to use a tool, as the coaches had no standard method of keeping track of which students had completed what. This also led to repeated competency evaluations, as documents would get lost and no record was kept to show what tools which students were competent with. Another goal of a tool training program would be to incorporate a method of reliably tracking which students were competent to use which tools.

Drawing from other Programs

As stated in their 1993 paper, Kraiger, Ford and Salas affirm that[4] "theories of skill development generally posit three definable stages: (a) initial skill acquisition, (b) skill compilation and (c) skill automaticity." The acquisition stage is defined by the transfer of declarative knowledge to procedural knowledge, followed by the compilation stage, which occurs as a trainee practices a skill and moves towards automaticity along a continuous spectrum. Due to the non-technical nature of the course, we would not expect students to reach automaticity, where "performance is fluid, accomplished and individualized"[4]. We would, however, expect students to gain basic descriptive knowledge regarding each of the tools in the tools boxes as well as procedural knowledge on a select few, characteristics of the acquisition stage and the early portion of compilation of skill-based learning. "With compilation, individuals are in a better position to determine the situation in which trained skills are useful…"[4], a desired outcome associated with students familiarizing themselves as much as possible with the design and construction processes.

University level courses were surveyed from both the University of Calgary and other universities within North America, with the intent of finding out what methods are currently being used by other facilities to accomplish similar training goals. As very few other courses exist which are similar to the design courses at the University of Calgary, information was collected not only from vaguely similar engineering courses (from first to fourth year), but also from other departments, and other institutes, such as the Southern Alberta Institute of Technology (SAIT) and Calgary area junior and senior high school construction shop classrooms. Although the tools used in these various laboratory settings differ in exact function, they are instruments which are used for a specific purpose, which can pose a hazard if used incorrectly or for the wrong purpose.

Some facilities, such as various Faculty of Arts laboratories at the University of Calgary have small enough student numbers that a single individual, who is experienced in the use of the tools available there, could explain and demonstrate the function of each of them in person. A similar walkthrough method was found in other university level department specific engineering design courses at the University of Alberta. This method has been found to be effective for these facilities, because the instructor is able to verbally explain and visually demonstrate proper operation of the tools, and is able to directly monitor all of the students because of the smaller enrollment. The only requirement in place for the students to begin using the tools is a sense of comfort by the instructor that the student is capable of operating the device without posing a high risk of accident. Although these methods may meet the needs of their respective institutes, it would be unrealistic to assume they could be effective for more than seven hundred students spanning across twenty four different laboratory sections, supervised by coaches who do not necessarily have a background in hand tool operation.

At SAIT, a similar walkthrough method of instruction is frequently utilized to introduce students to the tools found in the laboratories and shops. There is an additional component present in certain technical courses that has found success in terms of students practicing the use of a wide variety of tools. The students are given a project which spans an entire semester, where they are all expected to end up with a pre-determined finished product. The process of manufacturing the object requires the use of all of the tools in the laboratory. Individuals involved in the instruction of this course believe that it is successful because it gives a reason for students to use several less frequented tools which they may never be exposed to otherwise.

A program with similar method and goals was found in literature at the University of Idaho in their fourth-year capstone experience where[11] "graduate student mentors in the Idaho Engineering Works (IEWorks) have created a three-session orientation that teaches fundamentals of machining associated with the construction of a small multi-tool." The project "promotes awareness of manufacturing skills required to generate high quality hardware prototypes that satisfy the needs of industry customers" while developing "non-technical performance skills such as the ability to work in teams, communicate effectively, think creatively and act professionally." The project is an introduction project in the year-long mechanical engineering course and comprises a walkthrough-style orientation of the in-house machine shop as well as pre-determined machining procedures which all students engage in to create a pliers/screwdrivers multi-tool. An evaluation of the impact of the project found that by completing this project, students felt much more comfortable using the shop and its tools and felt more aware of the capabilities of the tools and processes available in the machine shops than before they had begun. Similar goals were desired for our program and the specific hand and power tools available to our students. Also, because our first-year design course is not department-specific, nearly seven hundred students would be taking part in this training (and more in years to come), and our laboratory coaches do not necessarily have the background knowledge and experience to go through the tool chests with their twenty to thirty students.

Junior and senior high school industrial arts and construction classes were also surveyed, as the tools found in those facilities are very similar to those found in our first-year design laboratories. Common practice in such facilities is to have students view a video regarding general workplace safety, and to have them write an examination on the rules associated with the tools out on the floor. An instructor for this type of course stated that, although their students would demonstrate some knowledge of the tools by writing a test, it was not until they were viewed using the tool properly that the instructor would feel comfortable with the student's skills. As a SAIT instructor noted, "Writing a test about bicycles does not mean that you know how to ride a bicycle." This can also be said for the tools in the design laboratory, although writing a test does demonstrate that a student has at least some background knowledge regarding a tool.

The University of Calgary's Department of Chemistry's laboratory safety program was investigated, and found to be quite effective. Before taking part in laboratory experiments, students are required to complete an interactive CD-Rom program, where they receive explanations, demonstrations and are tested on the regulations and procedures of the laboratories. The program includes effective demonstrations of proper techniques, and allows for user interaction. Although it does not involve a practice portion, students are closely monitored once in the laboratory by the instructor or teaching assistant. The content of the video portions of the CD-Rom were filmed on campus, in the laboratories that the viewer would be working in, using the same equipment and procedures that will be used by the student. In his 1982 paper, Heath affirmed this level of relevance to be an important part of training, as he states[7] "The opinion is that to effectively teach safe and healthful practices associated with a task the worker must be trained in his work environment with the tools, machines, processes, and materials he uses on the job, and among his fellow workers".

The general finding from the local organizations and institutes surveyed was that there is no standard method of giving students and workers the proper knowledge and skills to safely carry out their tasks. University of Calgary Safety Services were consulted throughout the development and implementation of the tool training program, and confirmed that although regulations apply to equipment and emergency procedures, there is no standard or code dictating what must be incorporated in a training process for students.

Before students can learn how to physically operate the tools in the laboratory, information regarding the purpose and proper operation of the tools must be presented to them. Although the walkthrough-style live explanation and demonstration by an experienced individual has been found effective for institutes with small numbers of students, it would be impractical to implement such a form of learning for the large numbers expected in engineering in years to come. While discussing computer-based training, Read and Kleiner claim that[5] "The time and money needed to develop the computerized instructional material can be substantial. For these reasons, computer-based training is best suited for training courses with large enrolment and stable content". Although the enrolment in ENGG251/253 is substantial, the projects pursued by the students are ever-changing. The tools available in the toolboxes are reasonably static, however their application with regards to the course content may not be.

In their paper regarding the training of orthodontic students in the technical procedure of positioning orthodontic brackets, Chen, Horrocks and Evans state[12] "The nature of video is such that more peripheral information may be conveyed through a medium where visual effects can be maximized". Chen et al. also argue that incorporating motion into the teaching of "skilled perceptual-motor acts"[12], such as orthodontic bracket placement or hand tool operation, can enhance its effects on the trainees. Chen et al. also note that "An advantage of video teaching is the facility for play back which allows students to review part or all of their teaching material as often as necessary, making learning flexible". This advantage includes multiple benefits in the ENGG 251/253 environment, where a video could be replayed for each of the different laboratory sections or by students and coaches who wish to review content.

Implementation

A competency based tool training program was developed which was implemented into the design and communications courses' curriculums beginning in the fall semester of 2006. The goals of the training program are to expose all of the students to the proper uses and operation of the laboratory hand tools, while allowing interested students to be deemed competent with any of the tools so that they may use them during construction times. The desired outcome of this is to minimize the potential for accidents in the laboratory while familiarizing students with processes found in applications of design engineering.

A video for the students and coaches was produced regarding the safe and proper functioning and operation of the tools in the design laboratories. Existing available video was surveyed, but it was found that content was often either too general or too specialized to be relevant to undergraduate engineers. Although general safety guidelines are consistent across most situations and environments, the technical skills associated with laboratory specific tools are not. Even when technical based videos were consulted, the tools used would have different features and details than those found in the design laboratories. According to Heath[7], the fact that the tools were different would decrease the relevance to the students, and therefore the effectiveness of the learning process.

To address the lack of appropriate media content for the training process, a tool training video was developed and produced in the design laboratories. Existing available laboratory equipment and technology was used in the process; filming equipment and editing software specifically. The focus of this video was to display content to the students that was relevant to the manner in which it would be applied. The footage was taken in the design laboratories, displaying the exact tools that are found in the toolboxes, being used for applications that will likely be encountered by the students. The presenter in the video is a second-year engineering student who has just finished the course; this was done so the students would feel on the same level as the presenter, further increasing the relevance on the content. Content for the video was collected from user manuals and online tutorials, as well as University of Calgary Safety Services, SAIT, Engineering Design Laboratory and Schulich School of Engineering Machine Shop personnel.

The video discusses fundamental safety, storage and operational procedures of the tools, and goes on to explain and demonstrate the proper use and technique of twelve of the skill based tools available. The content and applications in the video are based on situations likely encountered by the students. The video avoids dramatizations or content that could give the students a sense of exclusion, and instead focuses on script targeted directly to the viewer. The seventeen minute long content is broken down into fourteen chapters:

1. Laboratory Tools & Safety
2. Utility Knife
3. Metal File
4. Wood Chisel
5. Saws - General
6. Hack Saw
7. Back Saw
8. Coping Saw
9. Small Dovetail Saw
10. Keyhole Saw
11. Electric Drill
12. Tin Aviation Snips
13. Dremel Rotary Tool
14. Digital Multimeter

A procedure for deeming students as competent with the tools was developed to compliment the implementation of the tool training video. The challenge was to implement a practical method of assessing each student, while considering time constraints and the large number of students who would take part in it. A simple method of keeping track of student competencies was also put in place to increase the organization of the system as well as to reduce the likelihood of lost competency documents

An in-depth document was developed as a standard for the coaches, who will be assessing student competencies. The document comprises the ‘must-see’s’ that a laboratory coach must observe completed by the student before he/she can be deemed competent. The observations required include: appropriate safety equipment being worn, material and work area properly prepared, safe and skillful operation of the tool, and appropriate post-use actions taken. The specific ‘must-see’s’ vary between tools, and are therefore all listed individually.

A pair of documents was also produced to facilitate the recording and organization of completed competencies. One document was given to each of the students at the very beginning of the course and was to be kept inside the front cover of the students’ notebooks, referred to as logbooks. This document lists the tools that require completion of a competency test to use, and includes columns for coach signature and date upon completion. A goal of this document was to give the students a sense of ownership over their competencies, and will be in a location that should be present in the laboratory during all of a student’s respective laboratory times. There is also talk of having students keep their tool competency lists for further use in the fourth-year capstone design course. The second document is a simple master list which was to be kept by each of the coaches. On this grid format page, coaches can easily keep track of which of their students have been deemed competent with which tools for their own records, and in case a student logbook is lost.

Gaining access to the tools is an ongoing process for students. During the first laboratory of the year, students immediately view the tool training video chapters: Laboratory Tools & Safety, Utility Knife, Saws – General, Crosscut Back Saw, and Electric Drill. Students then proceed to take part in an open-ended tower building project. A component of this tower requires the use of the crosscut backsaw, utility knife and electric drill to produce. The tools are used by each student under close supervision of the laboratory coach, and the students have the opportunity to be deemed competent with any of these three tools at this point. The goal of having each student use these three tools is to familiarize them with the process involved in operating hand tools safely and effectively. During the next laboratory consisting of open construction time, the video is replayed, this time including the remaining chapters. From that point on, students may chose to demonstrate competency to their coaches with any number of the tools, in order to gain permission to use them for their projects. Students who have not been deemed competent by their lab coach will not be allowed access to the tools until they are able to show their coach that they can properly and safely operate the respective tool. The video is available for reviewing by the coaches and students online.

It is important that the coaches, who will be supervising the use of the tools and administering competency tests, know and understand the proper and safe functioning of the tools. Coach training takes place during the week before classes start in the fall semester each year, and a portion of this time will be allocated to the tool training system. Coaches will be educated not only on the process of deeming competency and keeping track of students, but also on the proper techniques and procedures associated with the tools in the toolboxes by taking part in the same tool usage projects that the students will be engaging, as previously mentioned. It is expected that the coaches will be competent with the tools themselves before administering an evaluation.

Evaluation

Coaches and students were surveyed regarding the impact of this tool training program on the students. Results of a survey conducted on the students mid-way through the two semester course can be viewed in the following figures:

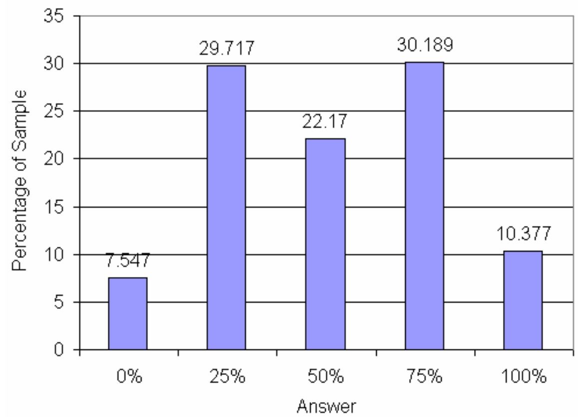

Figure 1: What percentage of the tools available in the tool boxes have you had personal experience operating prior to ENGG251/253? (n=212)

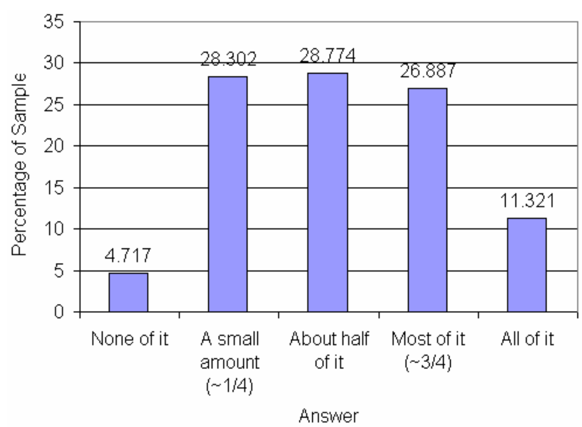

Figure 2: You were exposed to the tool video and the tool & Lego project at the start of the year. How much of the content covered in the two did you know before beginning ENGG251/253? (n=212)

From the data, some students claim to have a considerable amount of knowledge and skill associated with the hand tools, while just as many have very little; there seems to be very little consistency regarding the amount of hand tool knowledge students are entering into first year engineering with. It was also found that primary and secondary schools are the main source of basic hand tool training for students prior to university, but just over half of students have taken these respective courses, as they are frequently taken as electives. The same survey found that 33% of sample students state that their skills have not improved at all through the activities described, while the other two thirds attested to (anywhere from ‘some’ to ‘a lot’ of) skill acquisition during the first semester. Based on the results of the survey conducted, it seems that approximately one third of first year undergraduate students claim to be already accomplished in the hand tool skills and knowledge taught, while the other two thirds have essentially 'caught-up' with the former group through the program described. It was also noted by the coaches in the laboratories that a substantial amount of learning seems to take place during the project times when the students operate the tools, and have suggested implementing a regular weekly or bi-weekly event involving a 'tool of the week', where students gain experience operating a new tool each week, increasing the arsenal of skills and knowledge obtained by undergraduate engineers through these tools. It also could be said that the program has successfully increased the safety awareness of students, as there have been no injuries in the laboratories since the implementation of the program, compared to small numbers of cases (1-4) in previous years. While these small amounts of data do not statistically confirm this conclusion, observations made by recurring laboratory personnel support the possibility of significantly increased safety awareness in students.

Conclusions

As engineering education shifts towards providing undergraduate students with an open-ended, hands-on environment, we must make available to them the tools they require to manipulate the world for which they design. Tool training is central to hands-on learning in engineering and yet largely dormant in universities, which is unfortunate due to the large amount of learning that can take place from a few simple, hands-on exercises. The learning is experiential and multi-level in nature, familiarizing students with design considerations like tolerancing, dimensioning, surface finish, material removal and separation, safety constraints, and much more. Safety and proper tool operation go hand-in-hand, and if students are to have access to these potentially hazardous tools, they must also be educated on the safety considerations pertaining to them. By introducing hand and power tools into the undergraduate design environment, we cannot assume that accidents will not happen, but due diligence must be demonstrated. As these basic skills and knowledge are no longer being taught to all students before entering into university level courses, it is the responsibility of engineering educations to ensure that graduating students have at least basic knowledge and experience with the real-world construction process.

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