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# Improving the Knowledge Transfer Skills of Industrial Technology Students

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# Improving the Knowledge Transfer Skills of Industrial Technology Students

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## *Introduction*

Knowledge transfer is the ability to apply information learned in one context to new contexts. As such, knowledge transfer is a primary goal of educators in virtually every discipline. English teachers, for example, do not teach reading skills merely to allow students to perform well on their exams; rather, students are taught reading skills so they can read newspapers and other written materials during their everyday life. Similarly, we in Industrial Technology would like our graduates to be able to apply knowledge gained in our classrooms and laboratories to a wide range of equipment in industry.

Because applications of industrial automation take on many different forms, it may appear as though they are totally unrelated when in fact they often are related. It is quite easy, for example, for a novice to see few similarities between a Coordinate Measuring Machine (CMM) and an industrial robot because they are not similar in appearance, have vastly different operator interfaces, and perform seemingly unrelated tasks in the manufacturing environment. There are, however, many fundamental similarities between these two machines. For example, both machines use programming languages that have conditional branching commands, both use tool offsetting techniques, and both use the Cartesian coordinate system to direct machine motion. Because today's manufacturing professional may find herself responsible for solving problems on many types of automated equipment, it is clear that knowledge transfer skills are an important asset to such a person.

The unit of instruction described in this paper was developed by the author as part of a research project that had two primary objectives. The first objective was to identify and/or develop pedagogical strategies for teaching industrial automation that incorporate the cognitive science principles relating to knowledge transfer. The second objective was to develop and field test a specific unit of instruction for teaching the principles of the Cartesian Coordinate System as applied to Computer Numerical Control (CNC) machining centers, industrial robots and CMMs. The aforementioned study revealed that three principles are at the heart of knowledge transfer: (1) instruction should encourage students to learn conceptually; (2) instruction should be contextualized; and (3) instruction should help students understand the relationship between relevant conceptual and procedural knowledge (Devine, 2003). The unit of instruction described on the following pages was developed within this framework.

### **<u>Textbook Treatment of Cartesian Coordinate Systems</u>**

The researcher examined the instructional treatment of the Cartesian coordinate system in 47 textbooks written on the subject of industrial automation between 1968 and 2003. The textbooks were written for three general audiences: community college and trade school students who will likely become entry-level machine operators or programmers upon graduation; engineering students who will likely work as product designers or industrial engineers in the manufacturing workplace; and management students who may work in a non-manufacturing capacity (i.e., marketing, sales, information services, etc.) within a manufacturing company.

The majority of textbooks available for instruction in industrial automation focus on either CNC programming (Chang & Melkanoff, 1989; Curran & Stenerson, 2001; Krar & Gill, 1990; Lin, 1994; Lynch, 1992, 1993; Valentino & Goldenberg, 2000) or robot nomenclature, cell design, and interfacing (Asfahl, 1992; Fuller, 1999; Malcolm, 1988; Masterson, Towers, & Fardo, 1996; Rehg, 2003; Spiteri, 1990). When there is coverage of CMMs, it is very brief and general in nature; including topics such as CMM use in industry and the typical nomenclature of machines (DeGarmo, Black, & Kohser, 1997; Lin, 1994; Rehg, 2003).

Very little robot and CMM programming/operating information is provided in texts. Several factors may contribute to this condition. First, because CNC is a mature technology that has been embraced by virtually every industry, it has been a prominent course of study in many manufacturing education programs since the 1960s and many authors have written texts to tap into this market. Second, the CNC programming language and operating procedures are more standardized than are those of industrial robots and CMMs. Rehg (2003), for example, lists 16 different robot programming languages that have been developed by robot manufacturers since the 1970s. Because the structure of these 16 programming languages varies dramatically, it is difficult to develop textbooks that contain detailed robot programming instruction.

Coverage of the Cartesian coordinate system in the textbooks generally begins with some background information which often includes two-dimensional line drawings of the Cartesian coordinate system (usually in the context of CNC machining), definition of terms (i.e., origin, quadrant, axis, etc.) and the general rules for use, such as positive and negative direction, etc. References made to the associated mathematical principles falls into two general categories: mathematically intensive (i.e., presentation of three-dimensional matrices to describe the transformational shift in coordinate system origin and orientation); or definition-based (defined terms such as origin, axis, quadrant, etc.).

Textbooks having extensive coverage of Cartesian coordinate systems generally include a drawing illustrating how "significant points" on a sample workpiece can be assigned coordinates, along with specific programming commands for a machine tool (usually a Fanuc-controlled CNC machine). Two authors, Childs (1973) and Lynch (1992), made effective use of street map and graphing analogies to introduce the topic.
Of the 47 textbooks reviewed only seven address industrial robots, CNC, and CMMs (see DeGarmo et al., 1997; Foston, Smith, & Au, 1991; Groover, 2001; Kief, 1999; Kief & Waters, 1992; Luggen, 1991; Powers, 1987). Each of these seven texts presents a brief overview of the manufacturing tasks performed by each machine and typically states that the three machines use the Cartesian coordinate system. None of the seven texts contain treatment of Cartesian coordinate systems beyond definition of terms.

**Classroom Treatment of Cartesian Coordinate Systems**

Automation instructors from several NAIT accredited Industrial Technology baccalaureate programs were randomly selected and contacted regarding their in-class treatment of the Cartesian coordinate system. Most of the instructors indicated that they use a combination of textbooks, supplemental materials, and lab activities when teaching the Cartesian coordinate system. The supplemental materials generally include worked examples of programs, review of pertinent definitions (i.e.; quadrant, axis, etc.), and written homework assignments. An important aspect of the supplemental materials is that they include programming codes and worked examples for the lab equipment at their universities.

**Manufacturer Documentation and Training in Cartesian Coordinate Systems**

Original Equipment Manufacturers (OEMs) provide documentation (i.e. manuals) and training with each machine they sell. Included in the documentation and training are the detailed procedures and programming commands required to define and use Cartesian coordinate systems on their particular machines. Numerous machine tool and training manuals for CNC, industrial robots, and CMMs were reviewed by the author from numerous OEMs including ABB (ABB Robotics AB, n.d.-a, n.d.-b, n.d.-c), Cincinnati Milacron (Cincinnati Milacron, n.d.-a, n.d.-b), Fanuc (Fanuc Robotics North America, 1999), DEA (DEA spa, 1995), and Brown & Sharpe (Brown & Sharpe Mfg. Co., 1994).

As one might expect, the machine tool manuals were very procedural in nature. There was virtually no attempt made to describe the mathematical concepts behind the procedures, and there was minimal information regarding the potential use of the functions in a real-world application. The manuals made extensive use of two-dimensional line drawings and worked examples. Because many of the manuals were translated into English, grammar and context issues were sometimes problematic. In summary, the manuals and OEM training accurately describe the procedures for using the machinery, but they do little to help the reader gain a conceptual understanding of the content or application context.

## *Procedures Used to Develop the Unit of Instruction*

In an effort to improve knowledge transfer in the area of Cartesian coordinate systems in automation, the researcher developed a unit of instruction that involved computer mediated instruction (CMI), instructor demonstrations, and hands-on lab activities. The Problem Directed Instructional Design Methodology (Byers & Rhodes, 1998) was used to design the unit of instruction. The unit of study was reviewed using the three-step formative evaluation approach outlined by Geis (1987). Geis's formative evaluation approach includes two phases of developmental testing and one phase of expert review. The developmental testing phases used in this study (see Geis, 1987) are very similar to the new product testing performed in manufacturing industries (Geis, 1987; Schnackenberg, Chin, & Luppicini, 2000). In the manufacturing context, potential customers are asked to use a prototype product and give feedback regarding their perceptions of the product. In the context of instructional design, "Developmental testing employs naïve learners, i.e., potential students to simulate the consumer population" (Geis, 1987, p. 1) Authors generally recommend using a combination of two phases during developmental testing (Dick & King, 1994; Geis, 1987; Persico, 1997).

The first phase of review was a developmental testing phase that followed the "clinical strategy" which involves one-to-one interactions between the student and the researcher (Geis, 1987, p. 2). During the initial review, the "learners [were] asked to go through the teaching materials, indicating difficulties when they [occurred]; commenting on possible causes of such problems, and even acting as co-authors by suggesting changes which would improve the materials" (Geis, 1987, p. 2). The designer interacted a great deal with the learners to discuss the major points of the material (Dick & King, 1994).

The second phase of review was an expert review phase, during which feedback regarding the unit of instruction was obtained through individual consultation with the specialists. Per Geis's (1987) recommendation, three of the specialists selected were experienced educators who are knowledgeable in instructional design and knowledge transfer principles. The remaining three specialists were "master performers" in industrial automation. One specialist from the areas of CNC, industrial robots, and CMMs was selected to represent each domain. The automation specialists were asked to "indicate if the procedures being taught are actually the ones used on the job and if the examples being used represent frequent and critical incidents" (Geis, 1987, p. 3).

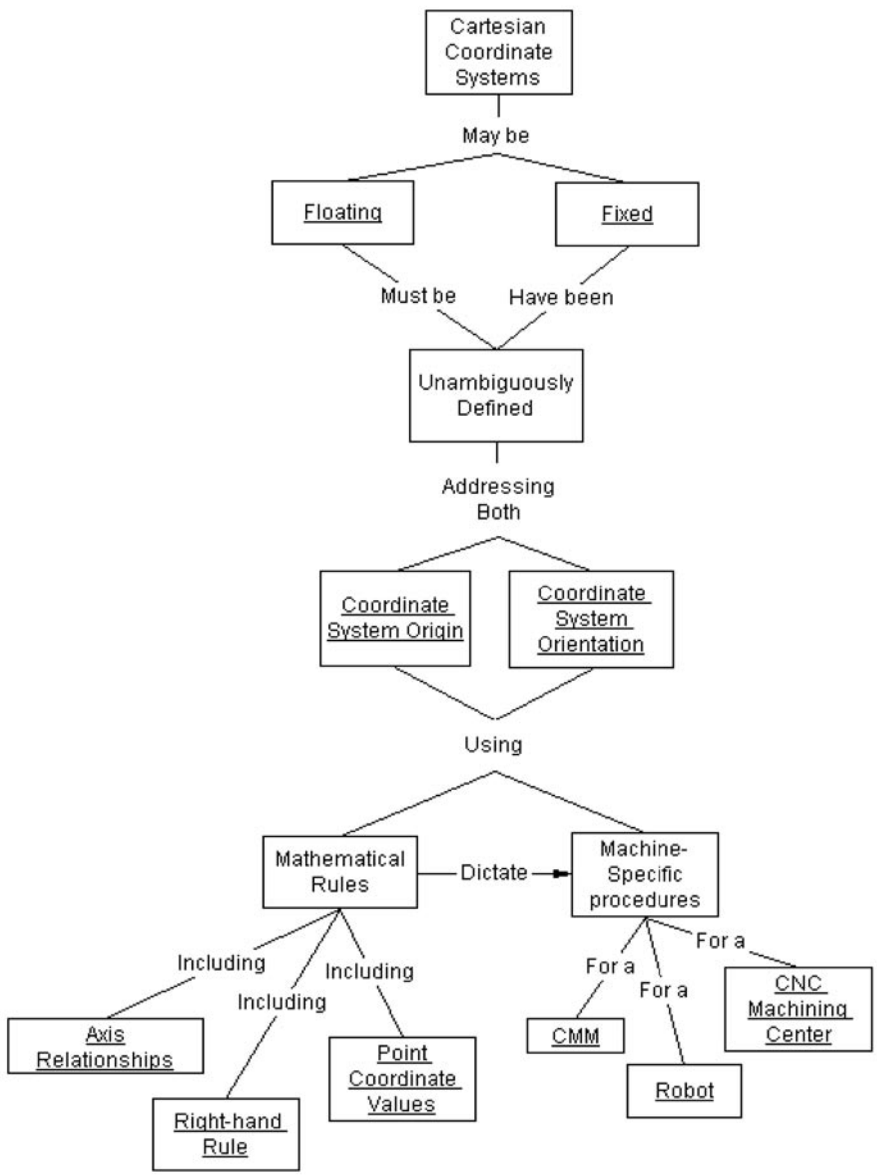
## *The Unit of Instruction*

The unit of instruction was comprised of three major components: (a) web-based Computer Mediated Instruction (CMI), (b) instructor-led discussions and demonstrations, and (c) hands-on, authentic lab activities supported by instructor coaching and modeling. The CMI was a web-based learning tool that was comprised of a series of web-pages integrated together using hyperlinks. The CMI served three primary goals: (a) it helped establish the context for the lesson; (b) it presented and illustrated relevant mathematical concepts; and (c) it presented and illustrated "generic" machine procedures with an emphasis on relating procedures to relevant mathematical concepts.

### The CMI

The initial page of the CMI was a concept map that served as an advance organizer and navigation tool (see Figure 1). The nodes (i.e., the boxes) that contain underlined text in Figure 1 were hyperlinked to subordinate pages that described and illustrated the concept represented by that node. Most of the subordinate pages contained many color illustrations which were used to illustrate worked examples,

***Figure 1. Initial Page from CMI***



mathematical concepts, or to illustrate conceptual ideas graphically (i.e., a visual metaphor).

The context of the lesson was introduced in the floating and fixed coordinate system nodes near the top of the concept map (see Figure 1). The subordinate pages associated with these two nodes presented descriptions of the concepts, multiple illustrations that showed how the concepts are commonly applied in a real-world industrial context, and presented and illustrated the advantages of using floating coordinate systems, using multiple illustrations of real-world examples.

In the CMI, deliberate emphasis was placed on making explicit the procedural characteristics common to most machines. This was especially important with Cartesian coordinate systems because the procedures used to define Cartesian coordinate systems vary considerably from one machine to another. For example, the procedures used to define coordinate systems on robots and CMMs share very few surface similarities. It would be very difficult for students to recognize the similarities between machines, which the literature suggests would encourage the students to learn the procedures in rote fashion.

There are two fundamental principles related to defining any Cartesian coordinate system: (a) The Cartesian coordinate system must have its origin clearly defined; and (b) the Cartesian coordinate system must have its orientation clearly defined. Any machine procedure used to define a Cartesian coordinate system on industrial machinery must include steps that define both the origin and the orientation of the coordinate system. Simply stated, machine procedures for defining Cartesian coordinate systems are designed to "answer" two general questions: (a) Where is the desired coordinate system origin located, and (b) what is the orientation of the desired coordinate system? The CMI presented a variety of machine procedures within the context of this common framework.

The manner in which the machine tool procedures define the orientation and origin of the Cartesian coordinate system varies from one machine to another and from one workpiece to another. In large part, the task a machine completes in the manufacturing workplace determines the procedures that are used. The CMM, for example, uses the extensive geometric calculation capabilities of the machine controller to define coordinate systems. CNC machining centers, on the other hand, have much more limited capabilities with regards to coordinate system manipulation. A variety of procedures can be used on most machines, depending on the requirements of the task at hand. Because the number of detailed procedures used by machines to define coordinate systems is quite large, it was not practical to define each procedure in the CMI. Once again common elements were sought and once again a relatively small number of mathematical rules were found to be the common element.

The CMI presented relevant mathematical principles using extensive illustrations and real-world examples. The examples contained hyperlinks to jump the learner to pages that described the machine procedures that use them. Also, when machine procedures were presented, there were hyperlinks available to take the learner to the pages that described the related mathematical principles. Using this technique, the relationships between machine procedures and mathematical concepts were made explicit to the learner.

The CMI did not present "detailed" machine procedures (i.e., press button A or go to screen B). Rather, the procedures presented in the CMI described and modeled the general thought process of how to apply relevant mathematical principles to define Cartesian coordinate systems on a particular machine and workpiece. The procedures were treated as specific examples of how the mathematical concepts may be applied to answer the two common questions regarding Cartesian coordinate systems: (a) Where is the desired coordinate system origin located, and (b) what is the orientation of the desired coordinate system?

Illustrations were used in the CMI as visual metaphors to represent abstract concepts that are difficult to visualize. The Cartesian coordinate system, for example, is an abstract concept that cannot be seen. There are specific rules or attributes that are used to describe the coordinate system, but the coordinate system itself cannot be seen. Figure 2 illustrates the symbol used throughout the CMI and lab exercises to represent the Cartesian coordinate system.

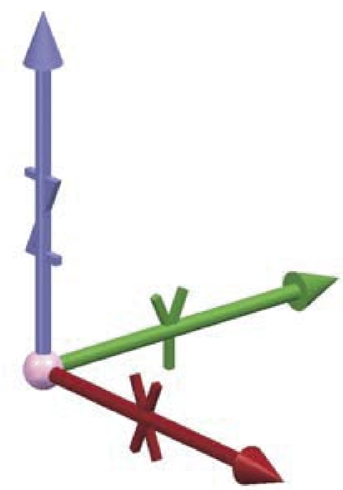



***Figure 2*. Symbol Used to Represent the Cartesian Coordinate System.**

Visual metaphors were also used extensively to describe the mathematical concepts that were related to specific machine procedures. Figure 3 shows an illustration that was used to describe the mathematical principles that enables a CMM to orient a floating coordinate system by measuring a hole drilled in a workpiece. The text boxes included in the illustration were not in the CMI, but they are typical of the method used to integrate text and graphics. This method of integrating text with graphics made it possible to explicitly describe the mathematical principles associated with machine procedures in a succinct and understandable manner.

The CMI used many illustrations to present examples of real equipment and workpieces. Figure 4, for example, illustrates a workpiece sitting on the table of a CMM. The illustration helps establish the context of the instruction that follows and helps visually orient the student. Images in the CMI were often shown at a larger scale to present the details of the lesson (see Figure 3 for an example).

Illustrations in the CMI sometimes omitted non-critical elements of the machine tools to help the focus the learner's attention. Figure 5 is a sample illustration from the CMI that shows only the principle components of a CNC machining center. In this example the machine's base, sheet-metal enclosure, and tool changer have been omitted. The machine's fixed coordinate system was shown in the illustration for reference. The text boxes in Figure 5 were included in the CMI.

Because the images used in the CMI were two-dimensional, it was not possible for students to rotate the images to see features on the back-side of an object. This made it difficult at times to illustrate concepts that involved more than one side of three-dimensional objects. Translucent renderings were created when such instances occurred. Figure 6 illustrates an industrial robot that has been rendered in both translucent and non-translucent modes. In this example, the fixed coordinate system location is visible only in the translucent image. Translucent images were also used to illustrate mathematical principles when describing procedures (refer to the cylinder in Figure 3 as an example).

**Instructor-Led Demonstrations and Discussions**

During the final phase of developmental testing an intact group of 15 students used the unit of instruction in a college course. Students worked in groups of four and five while completing the lab activities associated with the unit. The sample size of 15 students falls within the recommendations put forth by Dick & King (1994) and Schnackenberg et al (2000), and the groups of four to five students meets the recommendation of Geis (1987). The final developmental testing phase involved what Geis refers to as the "teach-and-test" method (1987, p. 3). Dick & King refer to this phase as the "small-group evaluation" phase (1994, p. 3). The main goal of this step was to determine if the students were able to successfully complete the activities presented in the sample unit of instruction and to identify areas that may have caused confusion. Relevant input from the initial and specialist reviews were incorporated into the unit of instruction before this testing phase began.

The instructor introduced the topic of Cartesian coordinate systems by facilitating a brief (10 minute) class discussion designed to bridge to prior knowledge and establish the context for the unit of instruction. Each student

***Figure 3*. An Illustration Used to Represent Mathematical Concepts**

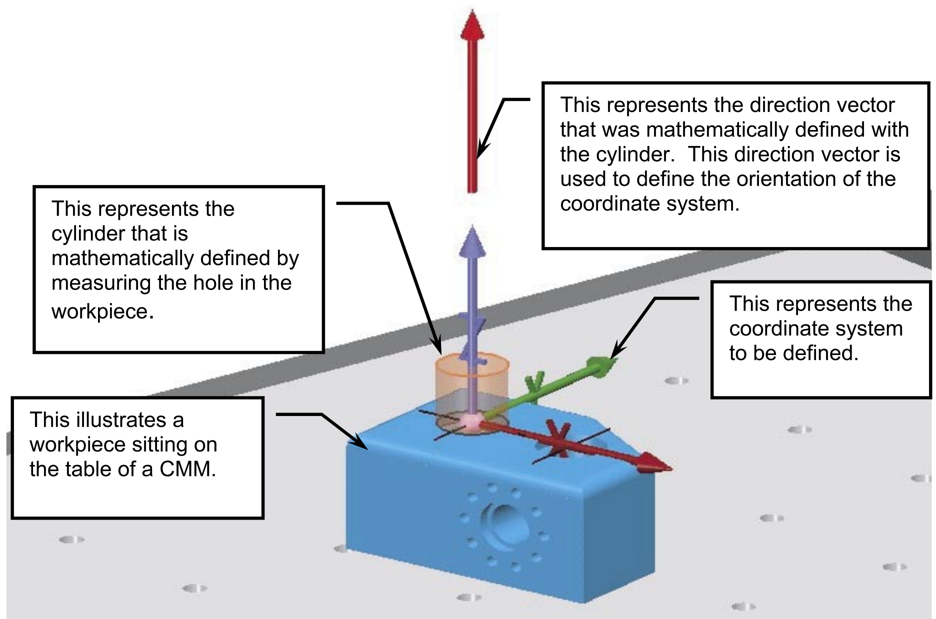
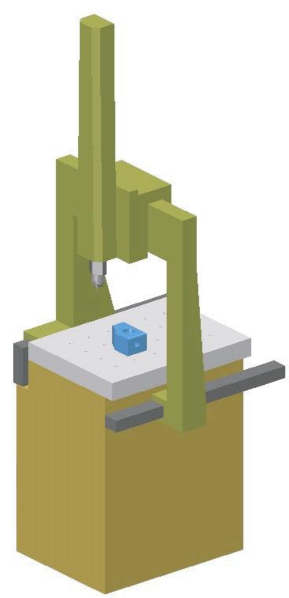



***Figure 4*. An Illustration Used to Establish Context and Orient the Learner**



was then given a CD containing the CMI materials and the students were asked to review the CD prior to the next period. No reading from a textbook was assigned.

At the beginning of the following class period, the instructor facilitated an in-depth class discussion that was designed to bridge to prior knowledge and further establish the context for the unit of instruction. The instructor asked open-ended questions regarding the Cartesian coordinate system in an attempt to activate the learners' prior knowledge structures. For example, the instructor engaged students in a discussion regarding previous CAD experiences that utilized the Cartesian coordinate system. The instructor also asked students about their knowledge regarding the basic mathematical rules pertaining to the Cartesian coordinate system as learned in prior mathematics courses. This line of discussion was not intended to review all of the pertinent rules, but to make the applicability of prior knowledge explicit to the students.

The instructor then conducted "concept demonstrations" designed to illustrate the application context for the lesson and heighten student interest in the subject. The demonstration was conducted in the form of a conversation with the students. The instructor asked guiding questions to help students recall relevant concepts and limitations from a previous lab activity in which students created a simple program on a robot that caused the robot to slide the gripper over and around two wires bent to form an upward-facing "vee." One limitation identified by the students was that the workpiece (the "vee") must be located and oriented in exactly the same place every time for their program to work properly. Also, to set up two workstations (two "vee's") would require that an entirely new program be written for the second vee. To help illustrate this idea, the workpiece that was used in their previous lab was moved to a new location within the work-cell. It was obvious to the students that their program from the previous lab would no longer complete the desired task because the part had moved.

The instructor asked questions to help students realize that floating coordinate systems would resolve the identified shortcomings of their previous programs. A wire model of the Cartesian coordinate system was used as an aid during these demonstrations to illustrate the location and orientation of the coordinate system as various scenarios were discussed. The color and shape of the wire model was designed to closely resemble the Cartesian coordinate system symbol used in the CMI.

The instructor handed out the lab procedures and lab questions which allowed student note-taking during the machine demonstrations. The instructor then demonstrated the basic procedures for creating floating coordinate systems on the robot, CNC machining center, and CMM. During the demonstrations the instructor asked many questions designed to activate

***Figure 5*. An Illustration Showing Only Critical Machine Components**

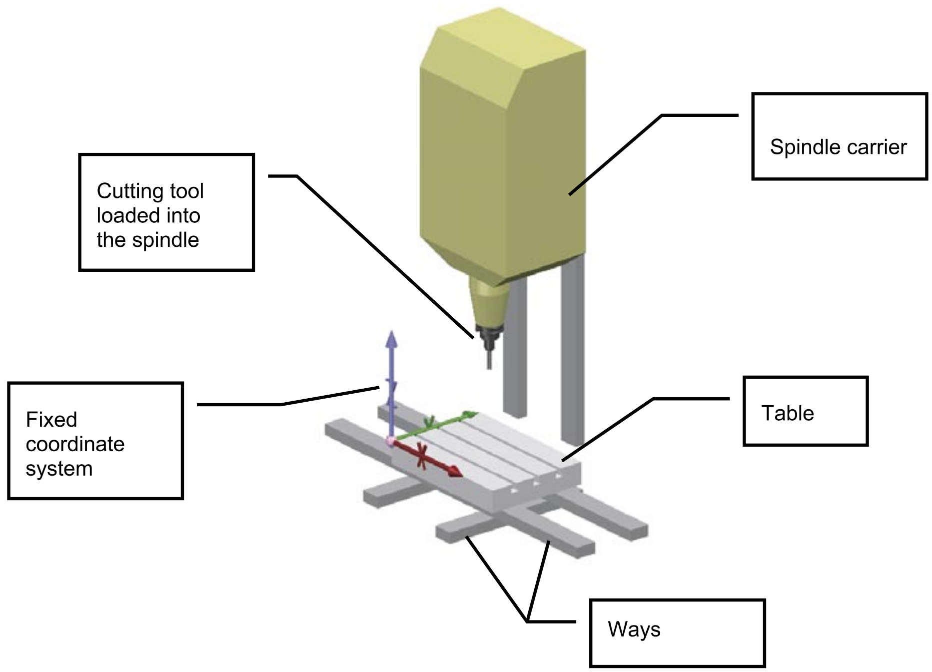
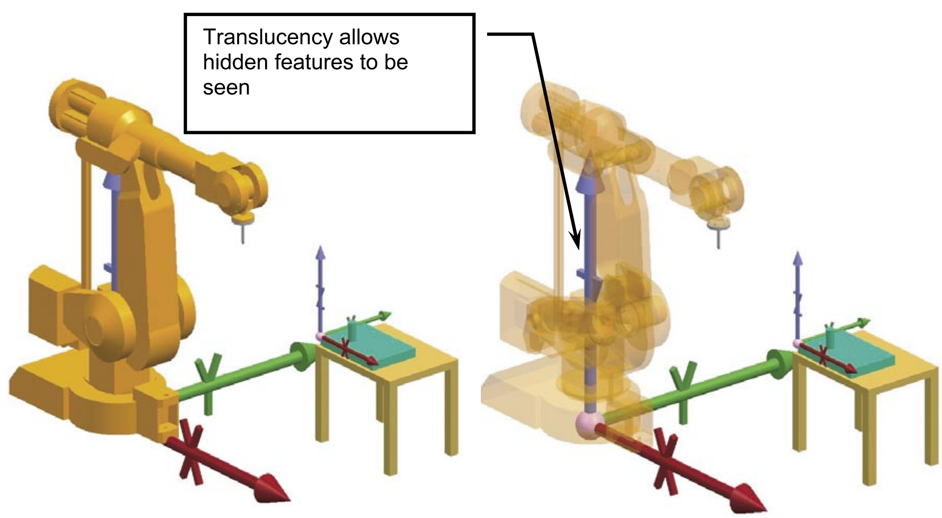



***Figure 6*. Example of Non-Translucent and Translucent Images.**



prior knowledge structures and relate the procedures being demonstrated to related concepts. For example, during the CNC demonstration, specific references were made to procedures that had previously been used by the students on conventional milling machines to establish an origin using a digital readout. The instructor used the wire model of the Cartesian coordinate system described above when demonstrating the labs on all three machines.

The instructor did not follow lock-step procedures during the demonstrations that the students were to duplicate. On the CMM and CNC machines for example, the demonstrations were performed on a workpiece the students would not use in their labs. On the CNC machine, the students were shown a coaxial indicator, but they were not shown exactly how to use it. They were encouraged to think about how they used other types of dial indicators and use that prior knowledge to figure out how to use the coaxial indicator.

In several cases, machine functions or commands were briefly demonstrated without using any workpiece. The students were then asked to determine how the demonstrated functions could be used to establish the desired floating coordinate system. The students were required to describe their plan to the instructor prior to starting the procedure during lab.

The instructor demonstrations focused on the thought processes associated with the machine procedures. Some of the specific procedures (i.e., exactly what buttons to push) were not discussed explicitly in the demonstrations. These details were provided to the students in the machine tool manuals and other written instructions. The instructor demonstrations were intended to be examples of how seemingly dissimilar machine procedures may be used to answer the two common questions regarding Cartesian coordinate systems: (a) Where is the desired coordinate system origin located, and (b) what is the orientation of the desired coordinate system?

**Hands-on Lab Activities**

The students worked in groups of four and five to complete a lab activity on each machine (robot, CNC machining center, and CMM). The groups spent two hours and 20 minutes on each machine over the span of three class periods. During the labs, the instructor moved from group to group answering questions, asking probing questions, offering alternative solutions for problems, etc. The instructor often asked "why" the student performed a particular step in the procedure. "Why did you select option A instead of option B?" The students were encouraged, and at times specifically instructed to explain to their peers why they had performed a particular task. "What problem did that procedure solve for you?" The wire model of the Cartesian coordinate system was frequently used by the students and instructor during discussions. The wire model made it possible for students to see and move the Cartesian coordinate system, which is otherwise abstract and invisible.

During the labs, the instructor explicitly pointed out opportunities to use prior knowledge (an instructional technique called embedded refreshment). The instructor also used probing questions to make explicit the relationships between procedures and mathematical concepts. For example, "Why were two points needed by the CMM to establish the X-axis while only one point was needed for the Y-axis?," or "Why did you teach the robot the +X and +Y-axes, but not the +Z-axis?"

After students completed all three of the labs, the instructor facilitated a 30-minute group discussion to talk about the labs and any points of confusion that may have persisted. Similarities between the three machines were identified and discussed. Reference to other types of machines was also made during the final discussion.

## *Student Feedback*

After completing the unit of instruction, the students participated in one of two group debriefing sessions. The group debriefing sessions were facilitated by a specialist from the University Assessment Office who is qualified to facilitate group discussions. The facilitator used six pre-written questions as a framework for each session. The facilitator and a note taker were the only persons in the room with the students during the debriefings. The purpose of the sessions was to identify and discuss the perceived strengths and weaknesses of the unit of instruction.

A pilot session with three students was first conducted to determine if the questions being asked gleaned the desired information and if the questions were confusing to the students. Several questions were revised and one question was added after the pilot session. The second group debriefing with the remaining 12 students who used the unit of instruction was conducted two days after the pilot session.

The students indicated that they saw many similarities with regard to the CMM, CNC, and robot. There were many comments suggesting they understood that all three machines were using the same Cartesian coordinate systems and related mathematical principles. The only real difference noted was in how a person communicates with each machine. The students also indicated that using the wire model of the Cartesian coordinate system during demonstrations and discussions was very helpful. They also thought the fact that the wire model resembled the shape and color of the symbol used in the CMI was quite useful.

In summary, the comments made by the students indicated they found the instructional unit to be helpful and easy to use. All three facets of instruction (i.e., CMI, instructor interaction, and lab activities) contributed to their overall understanding of the lesson content. The techniques used in the CMI to integrate illustrations and text, and the hands-on lab activities supported by instructor scaffolds were most often cited by the students as being helpful. Students commented that the labs became less difficult as they progressed because what they learned during the first lab was applicable in subsequent labs. This comment suggests that knowledge transfer was occurring.

## *Discussion and Conclusions*

The discussion regarding student feedback presented above was based on results obtained from the initial field test of the unit of instruction. As of this writing, the unit of instruction has been used during three course offerings spanning a calendar period of three years. Since the conclusion of the formal research project, informal student feedback has continued to be very positive. Students often comment voluntarily that they think the instruction helps improve their understanding of concepts and also helps them see the commonalities between machine procedures. Student performance during labs and exams also suggests that knowledge transfer is taking place at some level.

As the reader might suspect, the development of the CMI described in this paper took a great deal of time. It goes without saying that it is not practical for most instructors to devote such time and energy to the preparation of a single unit of study. Fortunately, computer-based instruction is not a required element in instruction that is designed to improve knowledge transfer. Less formal instructional units, and even spontaneous help sessions with students, can benefit from the same knowledge transfer framework used to guide the development of this unit of instruction. Because of the success of this unit of instruction the author has applied many of the instructional techniques described in this paper in other lessons and courses. White boards and scratch paper replaced the CMI with similarly favorable results. Impromptu use of probing questions and the avoidance of lock-step procedural demonstrations and lab assignments (when possible) also appear to have enhanced student learning.

This study demonstrated that it is possible to create a unit of instruction that is perceived by students to be helpful while also meeting the current recommendations regarding teaching for transfer. That is, the students in this study reacted favorably to all three instructional components of the unit of instruction: (a) an instructor who bridged to prior knowledge, modeled expert performance (both cognitive and procedural) and provided scaffolding for the learners throughout the learning activities; (b) CMI that bridged to prior learning, illustrated real-world examples focusing on heuristics (why) rather than explicit procedures (how), and used visual metaphors to make explicit the key relationships between concepts and procedures; and (c) authentic, hands-on lab activities on a CNC machining center, Industrial Robot, and a CMM. Finally, this study demonstrated that students can successfully complete conceptually difficult laboratory experiences without first witnessing a demonstration of lock-step procedures. A departure from the traditional procedure-oriented demonstration and project scenario holds much promise for enhancing the knowledge transfer abilities of Industrial Technology students.

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