

# **A Coherent-Tactile Approach To Teaching Manufacturing Engineering**

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## **1. Abstract**

Teaching manufacturing engineering represents a challenge in that many important classical and theoretical topics such as metal cutting must be augmented using practical and applied approaches. A tactile appreciation of theory serves both to reinforce the whole curricula and to encourage students to engage in their learning. Appropriate syllabus content, stimulating assignment topics, the introduction of cutting tools into the classroom plus designing all-encompassing laboratory experiments enables students to ‘cement’ together the ‘building blocks’ of theory. This approach helps students to visualize many of the complex geometrical aspects of cutting tools and better grasp the link between theory and practice. The synergism produced by this tactile teaching also helps reduce (attendance and enrollment) attrition rates by anchoring students in a tangible engineering world.

This paper presents the techniques used in the teaching of manufacturing to mechanical engineering students at the University of Tasmania. The paper highlights the curricula followed, practical (laboratory) experiments conducted and the variety of teaching aids used. Summative evaluation, collated in the form of questionnaires for Student Evaluation of Teaching and Learning (SETL), support the view that the teaching technique(s) adopted were not only effective but also relatively popular with students, outcomes reflected in class attendance rates and exam success.

## **2. Introduction**

Hands-on (experiential) learning has long been a cornerstone of undergraduate engineering programs<sup>1</sup>. A number of recent investigations have demonstrated how tactile approaches to teaching can be facilitated through designing instructional laboratory sessions that meet well-defined objectives<sup>1,2</sup> and by linking theory to observation even with resource limitations<sup>3,4</sup>. From an industrial perspective, technological developments in the field of manufacturing engineering require that conventional engineering curricula keep abreast with professional and technological development<sup>5</sup>. In this regard, manufacturing engineers must not only have relevant and sound technical competency but also possess effective personal and interpersonal skills allowing them to integrate with, and contribute to, a productive workforce from a very early stage in their career<sup>5,6,7</sup>. To achieve such goals, for example, problem based learning is typically used in engineering education to develop important engineering skills, like creativity and (simultaneously) link educational experiences to the real world<sup>8</sup>. For these reasons, there is an impetus to include many experiential and tactile learning approaches within formative manufacturing engineering instruction. This has occurred, for example, with curricula on

Computer Aided Design (CAD)<sup>9</sup>, Computer Integrated Manufacture (CIM)<sup>10</sup> as well as Production Control<sup>11</sup>. However, some manufacturing related Unit(s) of Study (UoS) forming part of bachelor of mechanical engineering degrees (not manufacturing specific), have curricula that tackle manufacturing not only from systems or automation perspective but also encompass significant amounts of fundamental topics such as metal cutting theory. In these circumstances, the challenge is to extend tactile learning to develop a sound appreciation of manufacturing. The fact that such curricula cover a wide spectrum of applied and fundamental topics necessitates that a coherent approach be adopted. Class teaching and syllabi must be integrated with well-designed laboratory sessions and supported by appropriate teaching aids.

In 1998, the University of Tasmania undertook the critical decision to combine its individual engineering programs under the umbrella of an integrated (larger) School of Engineering. This trend is one that has become familiar with the realities of today's streamlined engineering tertiary education. One view supporting such change is that integration not only allows for the trimming of duplicated administrative duties but also provides for the sharing of wider resources, a richer variety of teaching units in one school and the evolution of a multi-disciplined research capability across different branches of engineering. With this in mind, the 'newborn' School of Engineering still retained the basic streams of Mechanical, Civil and Electrical Engineering but did so in a way that is more inline with providing the multi-careered and -talented, approach expected in training today's engineers. As part of the Mechanical Engineering program, KNE353 'Manufacturing, Maintenance and Quality' is one UoS where approximately half the 13 weeks of instruction are dedicated to metal cutting and manufacturing systems. The remainder of this UoS is made up of Maintenance<sup>12</sup> and Quality (control) components. An intricate class timetable added to the challenges of teaching KNE353 since some lecture hours spanned allocated student lunch breaks. KNE353 builds on the basic hands-on machining undertaken by all engineering students in 1<sup>st</sup> year and serves as a preparation for the 4<sup>th</sup> year unit Advanced Manufacturing.

### **3. The Coherent Approach**

The teaching methodology presented in this investigation is believed to encapsulate effective teaching techniques across four basic factors believed to influence a student's formative learning experience. Figure 1 shows these components which are (1) syllabus (2) teaching aids, (3) instructional laboratory sessions and (4) modes of delivery for all relevant UoS information. The term 'coherent' stems from the belief that effective learning can best be instilled by critically examining all these facets of the formative learning process. To exemplify this, recent evidence suggests that the provision or denial of printed lecture notes to engineering students make little difference to overall performance<sup>13</sup>. In the ensuing sections, each of the four components that contribute to the coherent approach will be discussed with respect to the teaching of KNE353.

#### **3.1. Syllabus**

The first part of the syllabus was designed to allow students to gain a sound theoretical background in the fundamental aspects of metal cutting. Good appreciation of these topics sometimes requires three-dimensional visualization of complicated geometry spanning tool features and the chip-tool interface during cutting. To facilitate student learning, a tactile approach was adopted where practically possible. It is noted that usage of the term 'tactile' learning in this investigation broadly indicates that cognition is actively assisted or encouraged (in the learner) so as to allow a better appreciation or ability to practice the physical aspects of the knowledge learned.

Table 1 presents an outline of topics covered during the teaching. Syllabus content augmented with a tactile influence is indicated with an asterisk. These items are briefly summarized below.

- Theoretical coverage of generating motions in machine tools was complimented with a number of videos produced in the School of Engineering. Content covered fundamental processes such as turning, drilling, milling and shaping. The videos also simultaneously demonstrated the primary (cutting speed) and secondary (feed speed) motions during machining and whether these were imparted to the cutting tool or the workpiece. It was felt that this was an essential prelude to the syllabus since more than 40% of the students in this UoS were from overseas and audiovisual content presented assisted understanding where any language barriers exist. The fact that KNE353 effectively had no pre-requisites also necessitated that a basic level of understanding with regards to machine tool motions was required.
- The physical features of cutting tools so critical in the analysis of metal cutting were covered through a number of ways. (i) Real life tool holders were brought into the classroom and used in lecture slides. (ii) An adaptable paperboard model was used to help explain geometrical features of tools such as positive and negative rake angles, cutting edge inclination and chip flow (Stabler's) law. Figure 2 shows the use of this model, the idea of which was inspired from a machining<sup>14</sup> textbook. (iii) To promote independent learning, and also expose students to governing engineering norms, a relevant Australian Standard<sup>15</sup> had to be consulted (on-line) by students to allow successful completion of one assignment.
- An appreciation of the geometrical aspects of cutting tools provided the necessary introduction to Oblique and Orthogonal cutting processes and chip flow direction. Theory was explained with the help of the paperboard model (Fig 2) and tool angles were demonstrated using real-life tools. For example, the theoretical explanation of inclination angle in lecture slides was demonstrated by using a flat piece of card against the cutting edge (and normal to the surface on which the flat tool holder sits). Having graph paper on this piece of card provided a 'tactile' appreciation of the inclination angle. Figure 3 shows the relevant lecture slide.
- Coverage of chip formation and packing was assisted through use of chip samples collected from the School's workshop. These were presented in the classroom in small sealable bags. Figure 4 shows samples of the various chip forms collected including one of the bags used to present to them to the class.
- Forces in metal cutting were not only covered in theory but also incorporated into one of the laboratory sessions.
- For the treatment of tool life and tool wear, real life tools were brought into the classroom and also used in the lecture notes. This allowed learners to physically connect to the features being discussed.

After this detailed coverage of metal cutting theory, the lectures then moved to treat manufacturing from a systems perspective, or of the 'the bigger picture'. Almost every component of this subsequent treatment benefited in one way or another from tactile learning.

- A number of industry videos assisted in gaining a better appreciation of modern day manufacturing systems, particularly Computer Numerical Control (CNC) machine tools and industrial robots. This audiovisual content provided a tangible appreciation of the use of effects of highly automated machine tools and would (later) assist in discussing flexible manufacture.
- Videos of CNC machining centres in operation helped exemplify flexibility in tool changes and machine re-programming. At the same time, the (visible) ability of these machines to handle parts within certain size constraints and geometrical features (e.g., flats and cylindrical surfaces) also brought some (generic) similitude to capability of these machines. This served as a basic introduction to the topic of Group Technology (GT), while viewing industrial robots in operation (through videos) provided an appreciation of parts handling in manufacturing cells.

### 3.2. Teaching Aids

Some teaching aids were incorporated into the UoS to facilitate tactile learning and included:

- Video clips of general purpose machine tools and basic machining operations were produced in the School of Engineering.
- Industry videos of industrial robots and programmable machine tools, highlighting a range of issues such as design features, applications/operations and tooling systems, were sourced from industry.
- A large-scale paperboard model of tool geometry (Fig. 2) assisted in the description of tool nomenclature and illustrated differences between oblique and orthogonal cutting as well as chip flow direction (Stabler's law).
- Samples of machining chips were collected and taken into the classroom (Fig. 3).

### 3.3. Laboratory

Two laboratory sessions were introduced to reinforce the theoretical treatment. This practical component counted for 20% of the total marks for the UoS. Two laboratory reports had to be submitted to cover the laboratory work in addition to a short quiz. The relatively large number of enrolled students and availability of only a single three-hour time slot in the timetable meant that the laboratory sessions had to be well designed and implemented. It was decided that the best solution was to have each group of student's conduct two experiments in one block (2 x 1½ hours). Some points of interest regarding these are briefly explained below.

- Effective laboratory instruction by demonstrators was an important contributor to the success of the experiments. To prime both laboratory instructors for each experiment, each was provided with a folder that covered the theory being addressed in the experiments along with 'ideal' test data results.
- Laboratory sessions started with a five-minute quiz to query the aims of each experiment and also safety considerations. Quiz questions were provided to students at the start of semester. The aim of conducting the quiz was to encourage pro-active participation through reading of resource material (before attending). Conducting the quiz in the first minutes of each lab session meant that students attended on time otherwise they would forfeit the marks allocated (20% of the

whole laboratory component). This was very successful for allowing a timely completion of both experiments on the same day.

- ‘Surface Roughness’ Laboratory: This experiment aimed to (1) introduce a surface roughness measuring instrument, (2) familiarize students with the aspects (topology) of surface roughness and to (3) appreciate the influence of cutting speed on the roughness of turned surfaces. The laboratory handout started by explaining surface metrology and its implications with regards to engineered (manufactured) components. The features of machined surfaces were then covered before some measures of roughness were introduced. The final introductory part of the laboratory handout then described the formation and collapse of the Built-Up-Edge (BUE) in metal cutting and its effects on roughness. Students calibrated the measuring instrument before going on to obtain roughness values on a pre-machined work piece. This sample demonstrated the influence of different cutting speeds on the BUE. Through this tactile approach, not only was theory on surface topology covered but it was also linked (and demonstrated) with regards to practical machining operations. Figure 5 shows the experimental set-up used in this laboratory experiment.
- ‘Drilling Operations’ Laboratory: A second handout was prepared to cover this session which served to (1) introduce a cutting tool dynamometer, (2) provide familiarization with the geometrical aspects of twist drills and drilling operations and (3) allow appreciation of the influence of tool feed and tool coating on the thrust force and torque during drilling. The laboratory handout introduced drilling operations, twist drill nomenclature, twist drill materials and coatings before discussing drilling forces. In the practical part of the experiment, students were first required to outline the main features of twist drills (in the laboratory) on a large diameter (~50mm) twist drill. This large tool, presented in Figure 6, formed an ideal tactile method of familiarization with geometrical aspects that would have otherwise been too fine to appreciate on a smaller tool. A number of holes were then drilled and the forces and torques measured. The 9mm drills used in these latter operations were coated and uncoated and operated at a number of feed speeds (for the same rpm). In this way, the influence of both tool coatings and cutting conditions were tangibly experienced.

### 3.4. Delivery Modes

Under the coherent approach, maintaining active student engagement extends beyond the preparation of lecture notes, laboratory sessions and teaching aids to include how this information is interchanged. Maintaining effective delivery modes was achieved through the following processes.

- Virtually all lecture notes were presented to students (in class) using electronic media. This was adopted since the relatively large enrollments (73) meant that using a whiteboard was not going to be effective in assuring clarity of presentation in the lecture theatre. Moreover, the large proportion of graphic content (such as diagrams and tools images) used in such a manufacturing course meant that digital media was effective.
- To encourage attendance, all students were provided with a printed set of lecture slides on a lecture by lecture basis. Absent students could pick up a copy on the

day but not thereafter, unless good reason was shown. Although this presented additional preparation work on the part of the lecturer, it was believed to be more effective than allowing students to access a complete set of notes from day 1 and (possibly) encouraging (subsequent) low attendance.

- A text file named 'ReadMe\_Log.txt' was made accessible from the School server. Figure 7 shows the first few lines of this file. This log was updated as the unit progressed and helped students keep up with daily progress of the unit and any notices for assignments. This file could also be used to provide an erratum to any typographical errors that appeared in printed lecture slides.

#### **4. Outcomes & Discussion**

To assess the outcomes of the methodologies covered by KNE353, some information extracted from questionnaires of Student Evaluation of Teaching and Learning (SETL) are presented in Table 2. These statistical data, covering 53 respondents, were conducted at the end of semester (October 2004). The results generally indicate that learning was motivated in the unit and that the knowledge gained was deemed relevant to the future professional careers of students. The use of audiovisual content also contributed to learning. Overall, it is concluded that the teaching techniques outlined in this investigation were a success.

#### **5. Conclusions**

The ability to promote student participation and benefit from the formative learning experience is influenced by a number of factors of synergistic interdependence. These factors have been independently discussed and are syllabus, teaching aids, laboratory sessions and means of delivery (communication). To achieve a positive learning experience requires an effective coherent approach addressing each of these factors. The present investigation has demonstrated how a tactile and coherent approach can be applied to the teaching of manufacturing curricula. The end result is a good appreciation of the subject matter and its relevance to the 'real world'. Both these achievements are believed to be important contributing factors to the ability of 'newstart' engineers in effectively and easily integrating into the workforce.

#### **5. Acknowledgements**

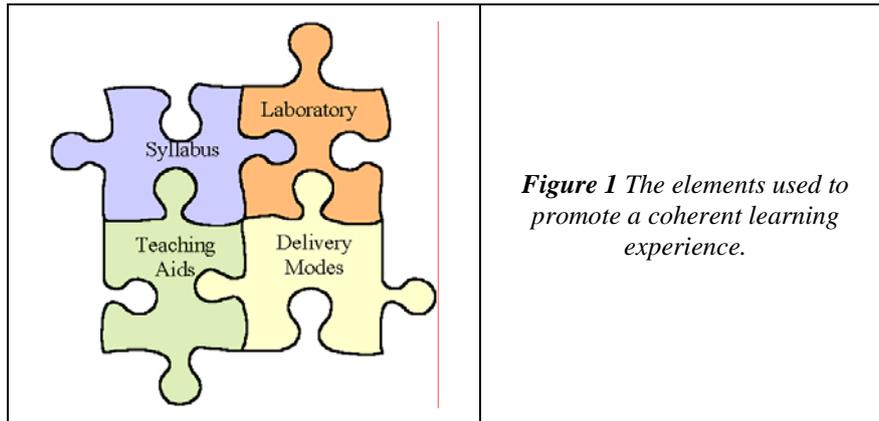
The following are gratefully acknowledged. Technical staff in the School of Engineering workshop, particularly *P. Seward* for assisting in the preparation of video clips for machining operations. *D. Butler* and *O. Wilkins* for laboratory instruction; *Dr K. Tossapol* (former post-graduate student) for contributing to the laboratory handout on Drilling.

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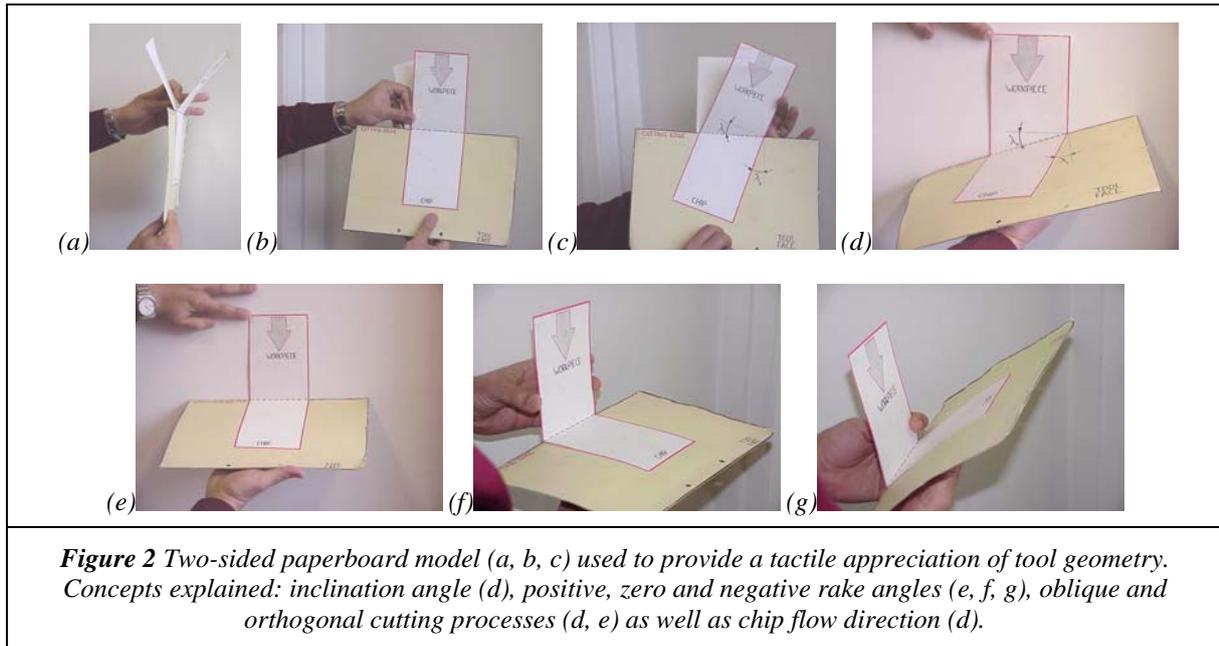
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**Figure 1** The elements used to promote a coherent learning experience.

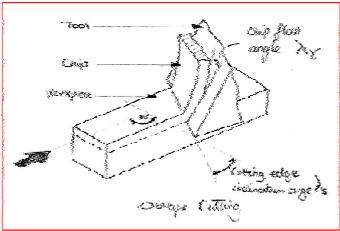
<b>Metal Cutting</b> (5 wks)	<p><b>Introduction</b></p> <p>(*)<b>Generating Motions in Machine Tools:</b> Primary, Secondary</p> <p>(*)<b>Single Point Tools:</b> General Definition, Typical Parts</p> <p><b>Resultant Cutting Motion</b></p> <p>(*)<b>Cutting Speed</b></p> <p><b>Geometry of the Undeformed Chip Section</b></p> <p>(*)<b>Material Removal Rates &amp; Machining time:</b> Cylindrical turning, Facing, Boring, Drilling</p> <p><b>Specific Cutting Energy</b></p> <p><b>Machining Power</b></p> <p><b>Drive system Efficiency</b></p> <p>(*)<b>Tool Nomenclature:</b> Introduction, AS 2217, Directions and planes (Tool-in-Hand &amp; Tool-in-Use Systems), Angles in the Cutting Edge Normal Plane (Rake, Clearance &amp; Wedge Angles, Effect of Resultant Cutting Direction on Angles in the Cutting Edge Normal Plane)</p> <p>(*)<b>Oblique and Orthogonal cutting</b></p> <p>(*)<b>Stabler's Law – Chip Flow Angle</b></p> <p>(*)<b>Types of Chip Formation:</b> Introduction, Continuous Chips (Primary and Secondary Deformation Zones, Chips with Built-up-edge), Discontinuous Chips, Chip Control, Chip Breakers: Groove and Integral Type, Chip Forms: Spiral, Straight, Arc, Tubular, Washer Type Helical, Needle, Spiral, Conical Helical</p> <p>(*)<b>Forces in Metal Cutting</b></p> <p><b>Ploughing Force</b></p> <p><b>Size Effect</b></p> <p><b>Cutting Ratio</b></p> <p><b>Shear Plane Angle</b></p> <p><b>Mechanics of Orthogonal Cutting:</b> Assumptions, Forces on the Tool Face, Forces on the Dynamometer, Forces on the shear Plane</p> <p><b>Friction, Heat and Temperature in Metal Cutting</b></p> <p>(*)<b>Tool life and Tool Wear:</b> Gradual or Progressive Wear (Adhesion, Abrasion &amp; Diffusion Wear), Premature Failure, Crater Wear, Flank Wear, Tool Life Criteria, Taylor Tool Life Equation</p>
<b>Manufacturing Systems</b> (2 wks)	<p><b>Manufacturing and Production systems</b></p> <p>(*)<b>Conventional Manufacturing Systems:</b> Job, Flow &amp; Project Shops</p> <p>(*)<b>Computer Numerical Control of Machine Tools:</b> Numerical control, direct numerical control, computer numerical control</p> <p>(*)<b>Programmable Machine Tools:</b> Advantages and disadvantages</p> <p>(*)<b>Tooling Systems on CNC Machine Tools</b></p> <p>(*)<b>CNC Machining Centres</b></p> <p>(*)<b>Flexibility in Manufacture:</b> Flexible Manufacturing Systems, Industry Case Studies</p> <p>(*)<b>Group Technology and Cellular Manufacturing:</b> Manufacturing Cells, Part Families (Introduction, Coding and Classification, Production Flow Analysis)</p>
<p><b>Table 1</b> UoS topics in metal cutting and manufacturing The asterisk refers to coverage that benefited from tactile learning.</p>	



### Metal Cutting: Oblique & Orthogonal

- **Oblique Cutting**
  - Examples of oblique lathe tools





Manufacture, Maintenance & Quality    Dr Yasar A. Adigüel    Semester 7, 2004  
 KME 353    Room 307

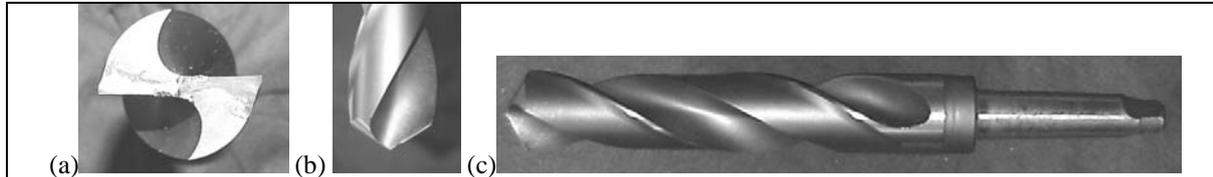
**Figure 3** Sample lecture slide. The theoretical explanation of inclination angle (right schematic) is being explained using the 'tactile approach' using a tool that was brought into the classroom. Also shown (left image), is the use of a piece of card placed touching the cutting edge to provide an appreciation of the inclination angle.



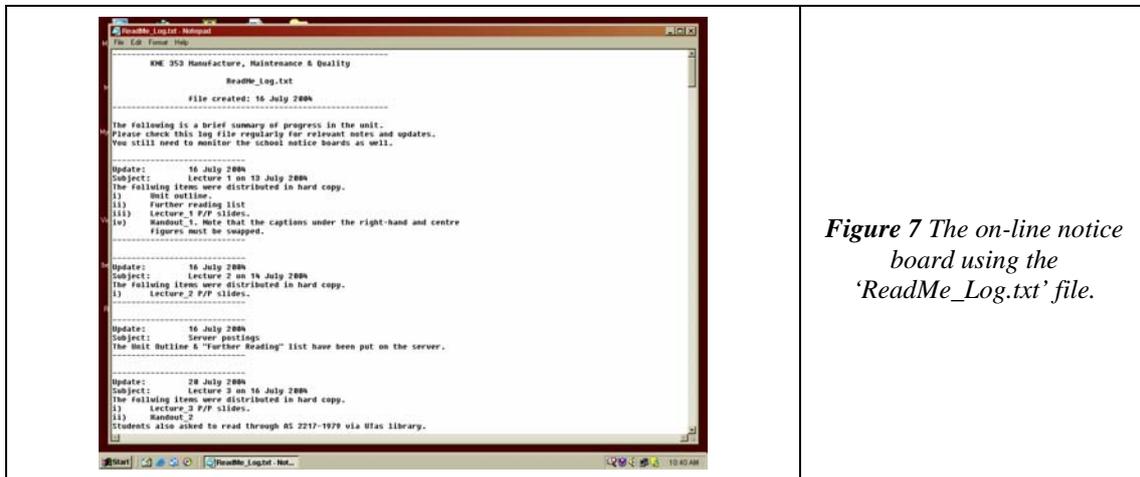
**Figure 4** Chip samples used to enhance tactile appreciation of chip formation and chip packing.



**Figure 5** The layout for the 'Surface Roughness' experiment and the workpiece used in the testing.



**Figure 6** The 50mm drill examined in the Drilling Operations laboratory. A number of features had to be pointed out (during classes and in submitted reports). Features are: drill body (c), shank (c), tool face (b), chisel edge (a, b), lips (a, b), margins (a, c), point angle (b), flutes (c), drill diameter (a), clearance diameter (a).



**Figure 7** The on-line notice board using the 'ReadMe\_Log.txt' file.

<b>Question</b>	<b>Mean Score (out of 5)</b>
<i>The printed set of lecture notes assisted my learning</i>	4.1
<i>The videos shown in class contributed to my understanding of the unit</i>	4.0
<i>The lecture material was well structured</i>	4.0
<i>Lectures were clear</i>	4.1
<i>The lecturer made good use of audiovisual materials</i>	4.1
<i>The workload in the unit was appropriate</i>	4.0
<i>The unit stimulated my interest in the subject area</i>	3.4
<i>I gained a good understanding of the subject matter</i>	3.7
<i>I enhanced my skills in this unit</i>	3.7
<i>I have learnt the relevance of this subject to my future profession</i>	3.8
<i>Practicals were a useful learning experience</i>	3.5
<i>The lecturer structured the material well</i>	4.0
<i>The lab manual assisted my learning</i>	3.7
<i>The lecturer communicated enthusiasm for the subject area</i>	3.9
<i>The lecturer motivated me to learn</i>	3.6

**Table 2** Sample results from SETL questionnaires.