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Development Of Learning Objectives For An Undergraduate Electrical Discharge Machining Technology Course Using The Delphi Technique

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DEVELOPMENT OF LEARNING OBJECTIVES FOR AN UNDERGRADUATE ELECTRICAL

DISCHARGE MACHINING TECHNOLOGY COURSE USING THE DELPHI TECHNIQUE

(TITLE)

BY

Aaron Harmon

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ABSTRACT

The purpose of this Delphi study was to develop comprehensive learning objectives that support undergraduates' acquisition of knowledge and skills of the Electrical Discharge Machining (EDM) processes and procedures. This study reflects learning objectives created for EDM. The learning objectives were derived by utilizing a panel of experts from academia and industry involved with EDM. The results of this study are intended for use when creating an instructional module for undergraduate machining studies.

A panel of experts was chosen through recommendations from members of an engineering and technology listserv. Two successive rounds of Delphi instruments were utilized to complete a comprehensive list of very necessary and extremely necessary learning objectives. These learning objectives are recommended by the panel of experts for use in an undergraduate level EDM course.

While the Delphi method was a successful tool in compiling these learning objectives, the researcher has made recommendations for further research in this area.

ACKNOWLEDGMENT

This work involves contributions from a variety of people. Whether large or small, all contributions were valuable for its completion. I would first like to thank my family for their support and constant reminders until the completion of this study. Equally important, I would like to thank the nominators whom began this study by providing experts in the field of EDM. Without these experts the success of the study would not have been possible.

Great thanks must be given to these experts whom participated throughout this study. These experts freely gave hours of their time and expertise, making an invaluable contribution. I would again like to thank these experts for their time and interest in my study.

My committee has led me through this study one step at a time. From the first meeting until the last, countless changes have been made, creating a successful and useful study. The committee always showed enthusiasm and interest while providing me with constant ideas and feedback. Without this it would not have been possible. The members on my committee, Dr. David Melton, Dr. Lance Hogan and Dr. Tom McDonald, have been both constructive and encouraging in directing this study. Thank you for all your hard work and guidance.

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CHAPTER 1

INTRODUCTION

Electrical Discharge Machining (EDM) is a non-traditional machining (NTM) method that utilizes electrical energy to remove material from a workpiece (Tsai, Yan, & Huang, 2003). A power supply produces a high frequency of electrical pulses that travel between an electrode and a workpiece. As a result, metal is thermally eroded and/or vaporized and flushed away by a dielectric fluid. Likewise, dielectric oil or dielectric water serves as an insulator between the electrode and workpiece and as a coolant.

EDM has become very popular because of its ability to machine very hard materials such as tool steels and carbides; although, materials must be conductive because of the use of electrical current. Not only is EDM an excellent choice for hard materials, it is excellent for machining complex shapes and designs (Brink, 1999).

Since the inception of EDM, many enhancements have been incorporated into the process and equipment. There are two basic types of EDM processes: die-sinking and wire cutting. Both processes have the same principles, but use different machining methods and/or types of electrodes. In die-sinking, an electrode commonly made of copper or graphite is fed into a workpiece to make an inverted replica. In wire EDM, a wire electrode is held between two points and fed into the workpiece for a desired contour (Charmilles US, 2004).

Through Eastern Illinois University's Technology program, courses incorporate industrial processes and machines for the advancement of education of its undergraduates. These machines offer an opportunity for a variety of skills and concepts found in many areas of industry. A die-sinking, Hansvedt Model SM-150B EDM housed in the machining production lab is the root cause for this research. The Hansvedt equipment was purchased in 1983 and has not benefited undergraduates for the lack of an instructional module. While the EDM processes and procedures are beneficial to undergraduates, little research in the development of effective EDM instructional modules with comprehensive learning objectives has been developed.

Statement of Purpose

The purpose of this study will be to develop comprehensive learning objectives that support undergraduates' acquisition of knowledge and skills of the EDM processes and procedures. Figure 1 shows the Hansvedt Model SM-150B EDM that is housed in Eastern Illinois University's Production Lab.

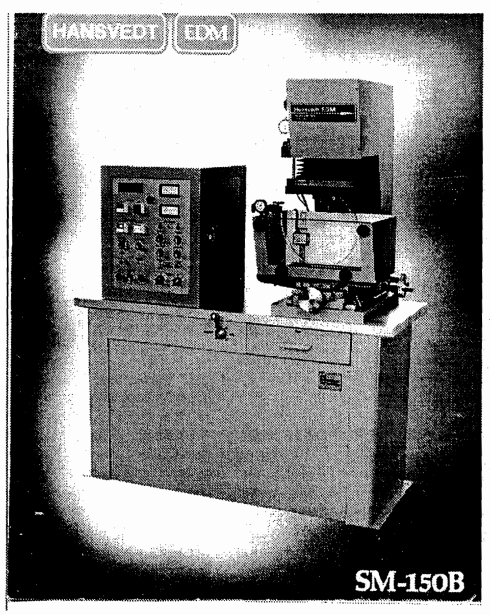

Figure 1. Hansvedt Model SM-150B (Hansvedt, 1982)

Problem Statement

While access to this machining process has been available to Eastern Illinois University's School of Technology for 25 years, EDM is not included in any undergraduate curriculum. With EDM's continued growth, industry knowledge of the machining processes and procedures will become more valuable. The availability of the EDM machine in Eastern Illinois University's Production Lab incorporated with the Delphi Study technique, provides an opportunity to investigate the development of comprehensive learning objectives to gain knowledge and skills of the EDM processes and procedures.

Research Question

The following research question was analyzed during the study to determine practical significance of the development of learning objectives in regards to EDM. What electrical discharge machining (EDM) learning objectives have practical significance for college students preparing for industry?

Justification

This study gathers information and opinions of various experts for determining the best learning objectives for instruction of undergraduates in the technology field. Because of old machinery, maintenance costs and the complications involved in provisions and execution of an EDM process, the process is not taught to many undergraduates.

Results of this study will allow other universities and technology institutions access to learning objectives for the creation of an instructional module for the use and understanding of basic EDM. Developing an understanding of what happens throughout the EDM process, along with problems which may arise, are the first steps in using EDM.

Definition of Terms

Arc: The flow of electricity across the gap between the electrodes and the workpiece.

Arc Gap: The space between the electrode and the workpiece where EDM occurs.

Contamination: Particles and debris found in the dielectric fluid that reduces its effectiveness.

Discharge: Controlled flow of current across a gap causing a spark.

Deionized Water: Water that has had the ions removed.

Deionized Oil: Oil that has had the ions removed.

Dielectric Fluid: A liquid of low conductivity, which acts as a coolant to solidify particles and then flushes them out of the working gap.

Dielectric System: Dielectric liquid is circulated to remove contamination and control debris size in the working gap during machining. This system is composed of a pump, filter, hoses, tank, and gauges.

EDM: Acronym for Electrical Discharge Machine or Electrical Discharge Machining. EDM is a process for eroding and removing material by transient action of electric spark on electrically conductive materials.

Electrode: Electrically conductive tool used to carry current to the workpiece material.

Electrode Wear: The amount of electrode material consumed during the EDM process.

Ionization: Occurs when the dielectric fluid becomes conductive after being subjected to high voltage.

Material Removal Rate: The volume of workpiece that is removed in a given unit of time (e.g., cubic inches per hour).

Nontraditional Machining: Processes in which there is a nontraditional mechanism of interaction between the tool and the workpiece; processes in which nontraditional media are used to affect the transfer of energy from the tool to the workpiece.

Precision: Consistency of results in repeated experiments.

Traditional Machining: Direct mechanical contact between the tool and the workpiece.

Hansvedt, (1996)

Delimitations

Only experts nominated from academia and industry will be utilized in the creation of EDM learning objectives for this study.

Limitations

Two limitations will be considered, the first being a small sample size of experts. Secondly, the experts will have little knowledge outside of their realm of either academia or industry. A third possible limitation might be mortality or lack of response to successive rounds.

Assumptions

An assumption will be made that the panel of experts do not know each other and will not communicate during the study.

Summary

EDM is a machining process that has been around for many years and since the 1980's, has become very important to industry. Many graduates from Eastern Illinois University are finding careers in industry where knowledge of the EDM process is important. This knowledge will allow a more versatile and knowledgeable person to advance in their respective company. By constructing learning objectives, this valuable process can be taught with greater success to undergraduates giving them an advantage over others seeking careers involving EDM.

CHAPTER 2

REVIEW OF LITERATURE

This review of literature is related to EDM principles and processes, learning and training modules and learning objectives that will support the later development of an instructional module for EDM. Articles were found pertaining to the EDM process, the development of instructional modules and Mager's learning objectives. In addition, the review included resources related to Delphi study processes and procedures.

Resources utilized where EBSCO host, which searched applied science and technology abstracts, academic search premier, business source elite and social sciences abstracts. Many websites were reviewed for information regarding the EDM process, which included detailed diagrams for demonstration. Additional resources were compiled from Eastern Illinois University Library and through Interlibrary Loan.

Another resource was Group Tool and Die located in Bloomington, Illinois. This facility houses seven EDM machines, including one controlled by Computer Numerical Control (CNC). All EDM equipment was operated by a very knowledgeable operator. This operator was able to provide valuable information about how EDM is used in industry. A tour allowed for viewing and understanding of different types of EDM; such as die-sink EDM with rotating heads. Also viewed were three different customer orders that required EDM with an explanation of how the orders would be completed.

Little information was found regarding the creation of instructional module learning objectives for EDM. However, articles reviewed provided enough tangent information to complete a thorough study.

This literature review will contain seven areas including: (a) EDM processes and principles; (b) types of EDM uses and advancements; (c) Bortz's learning module; (d) technologically based curriculum development; (e) Mager's learning objectives: (f) EDM based instructional module development; and finally, (g) Delphi study techniques and processes.

EDM Processes and Principles

In the year of 1770, English Chemist Joseph Priestly discovered that electrical discharges could have an erosive effect on certain metals (Ho & Newman, 2003). This phenomenon was not applied until 1946 when EDM was first marketed and used in industry (Olivo, 1987). Since then, advancements in EDM equipment have taken place although the EDM process uses the same basic principles.

A die-sinking EDM process begins with a machined electrode that is the mirror image of the final desired shape. This electrode is then placed into an electrode holder on the EDM die-sinking ram. A workpiece is then clamped into a vise or fastened directly to the X-Y table. To begin machining, the ram feeds toward the workpiece, which is submersed in dielectric oil. As the electrode comes close to the workpiece, the dielectric oil changes from an insulator to a conductor and allows voltage to "jump" across the dielectric oil (Hansvedt, 1982).

Material erosion occurs when electrical energy being utilized as thermal energy melts the workpiece into tiny fragments through thousands of tiny electrical charges (Tsai, Yan, & Huang, 2003). Flushing dielectric oil then washes away the dislodged material. Thermal energy created from the electrical pulses creates a channel of plasma between what can be called the cathode (workpiece) and anode (electrode) (Ho &

Newman, 2003). This area of erosion is "hit" with up to 200,000 electrical pulses per second, which can cause temperatures to rise as high as 36,000 °F (Hansvedt, 1982; McGeough, 1988). Because of the thousands of tiny repeated electrical pulses, EDM becomes a very precise machining technique that removes a very small amount of material. Typically, the amount of material removed per discharge ranges from .000006–.0004 mm^3 and the material removal rate (MRR) ranges from 2-400 mm^3/min depending on machine settings, finish required and the electrode material (Kalpajian & Schmid, 2003).

Types of EDM, Uses and Advancements

Since EDM's inception 60 years ago, advancements have widened the uses and usability. The principles of EDM have spread into Wire Electrical Discharge Machining (WEDM), Electrical Discharge Milling, Electrical Discharge Grinding, Electrical Discharge Dressing, Ultrasonic Aided EDM and Abrasive Electrical Discharge Grinding (Brink, 2000a).

These processes have individual pros and cons that make a variety of machining processes faster and more cost efficient, often with greater precision. WEDM is a popular type of EDM because of its ability to "carve" intricate designs. Different wire diameters can be used depending on the need for the workpiece. Wire is continually fed through the workpiece keeping a constant diameter, since electrode wear will take place (Puri & Bhattacharyya, 2003). Another advancement associated with WEDM is the use of dielectric water as opposed to oil. Dielectric water flushes over the un-submersed workpiece and exhibits similar characteristics and properties of the oil flushing process with a lower cost.

EDM has become popular in industry because of its precision and time/cost saving potential. EDM is used extensively to machine heat-treated materials. Once a material is heat-treated it becomes relatively hard and difficult to machine. EDM has no regard for the hardness of material, so the hardest tool steel can be machined with no worries of distortion, typically caused by annealing and reheating through traditional machining (Arthur, Dickens & Cobb, 1996). This allows expensive parts to be fixed and reused as opposed to being scrapped. EDM allows for intricate products to be produced as a result of mechanical and thermal stress being eliminated (Weng & Her, 2002).

Furthermore, Micro-EDM has revolutionized the drilling of very small holes. The smallest hole that can be made with laser machining measures 40µm, while micro-EDM can accomplish a hole just 5µm (Masuzawa, 2000; Rajurkar & Yu, 2000).

Finally, ceramics can be machined with ease using EDM. Ceramics, which commonly are hard to machine, can be done with EDM since the binding material is conductive (Hansvedt, 1982). This saves time, money and broken parts that can be salvaged.

EDM became an even greater advantage over other processes in the 1980's when computer numerical control (CNC) began controlling the EDM process. This allows complex designs to be consistently machined without an operator (Ho & Newman, 2003). This way, one operator can set up many machines and have them all operating at once.

A new type of electrode material is advancing the EDM process. It is being tested and has very little erosion and a higher metal removal rate than copper-tungsten. This new material uses a metal-matrix-ceramic (MMC), ZrB2/Cu, where erosion rates are significantly less than that of copper and graphite while still cheaper to manufacture than copper-tungsten (Brink, 2000b).

Next, using gas as opposed to dielectric fluid is being research and developed. Although the type of gas is not mentioned, it has been found to be an insulator equal to dirty EDM fluid. It is used to remove molten metal and ions from the workpiece surface while clean gas between the electrode and the workpiece can be achieved by introducing pressurized gas through the electrode (Brink, 2000b).

Finally, research is being done for using EDM to machine non-conductive materials. By using an electrolyte as the fluid and applying a thin metal coating to the non-conductive workpiece, EDM can be administered on such materials as silicon nitride (Si3N4). This metal coating allows electrons to flow while the presence of it is negligible (Brink, 2000b).

Bortz's Learning Module

Bortz's Learning Module, which is the framework for the results of this study, was developed many years ago. The module has never been published, but is an excellent resource (R.L. Hogan, personal communication, November 9, 2006). Bortz's module consists of two phases that encompass seven steps that are depicted in Figure 2.

To begin using Bortz's module one must analyze the learner in the present. It must be decided what the learner knows and what the learner needs to know after the learning module is completed. This must be completed so the learning objective can be achieved based upon activities presented in the training.

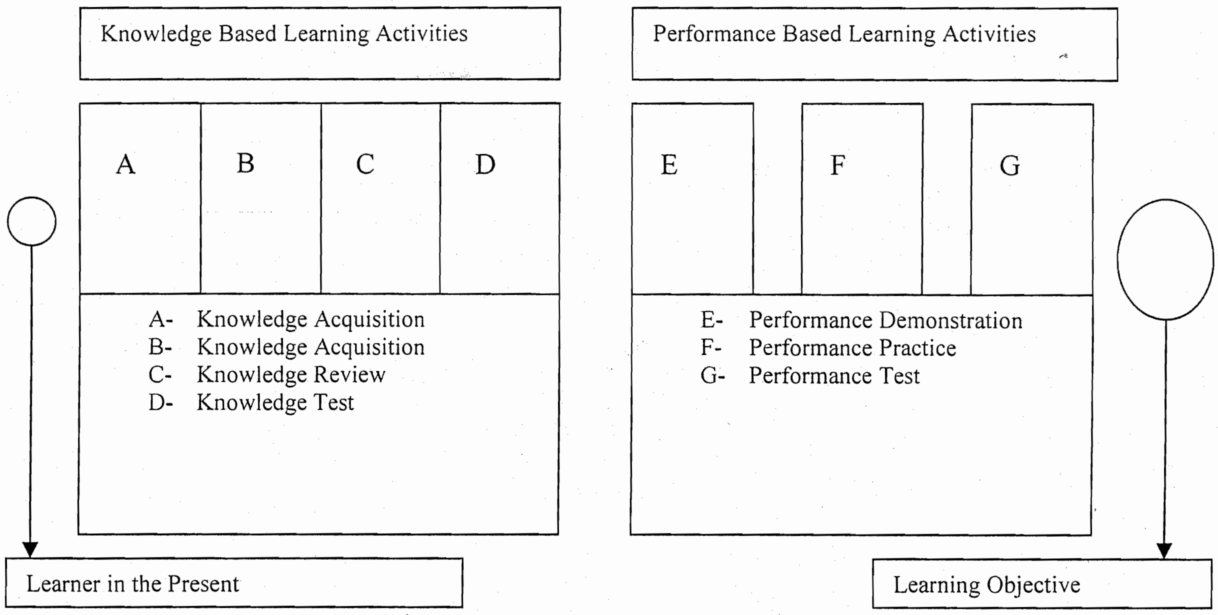

Figure 2. Bortz's Learning Module (Bortz, 2000; Hogan & Kuchar, 2006)

Knowledge Acquisition begins the Knowledge Based Learning Phase with steps A-B. These steps allow learners to gain all pertinent information in order to achieve the learning objective. This information not only needs to be thorough, but it needs to consider what learners presently know. Step C, Knowledge Review, allows learners a comprehensive review over the Knowledge Acquisition information. To finish, the learner must complete and pass a Knowledge Test. The test given must be reviewed for validity, reliability and an achievement level that concludes successful completion of the module. The purpose of the test is to evaluate learners' abilities to retain information from steps A-B (Hogan & Kuchar, 2006).

Moving into the Performance Based Learning Phase will allow the learner a hands-on approach. Step E consists of a Performance Demonstration that allows learners to view the process or machine in operation. Performance Practice, step F, gives learners a chance to apply what they have learned and seen to a real situation where they are able to practice hands-on.

The last step, step G, will evaluate the entire module with a Performance Test. Learners must show that they can operate the apparatus based upon what has been learned through the module. If they pass this phase it can be considered that they have mastered the process and the learning objective was accomplished (Hogan & Kuchar, 2006).

Technology Based Curriculum Development

As technology becomes more important in today's society, education for technology must stay pertinent. This is expressed comprehensively by Jones and Moreland (2003):

> Technology is a major and, some would argue, a determining feature of the world we inhabit. In consequence, young people, as future citizens, need to understand how it shapes the world and how they can participate in it. If future citizens are to understand and participate in decision-making, technology education must prepare them adequately by dealing with the technical, social, ethical, political, and economic issues that underlie technological process and by ensuring that students recognize that technology is located within a philosophical, historical, and theoretical context (p.53).

To achieve this model of young citizens, proper instructional modules with appropriate learning objectives must be devised for curriculum. Curriculum development is a project that forms identities, which can be found in three sectors:

knowledge, action and self. A general schematic of these sectors can be seen in Figure 3.

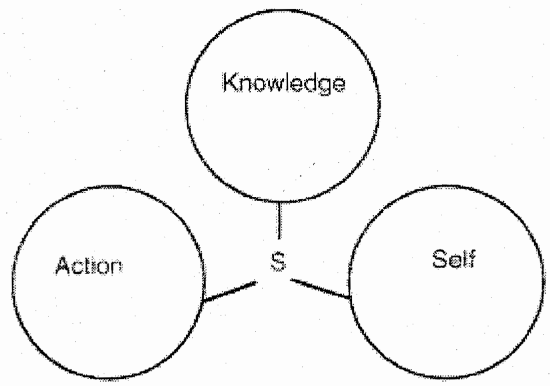

Figure 3. Curriculum: A general schema (Barnett, Parry, & Coate, 2001)

The knowledge sector refers to curriculum components that require discipline-specific competence and parts of teaching and learning that develop subject specialists. Action can be described as competence derived from physically doing an activity, such as creating a project on the EDM. Lastly, the self sector represents the development of educational identity with relation to the subject area. A student learning the operation of EDM could identify themselves as a machine operator or an ample production manager (Barnett, 2001).

Weights given to these sectors differ relative to which type of curriculum is being developed. After each sector has been described, the focus is directed toward integrating each sector relative to a technology curriculum.

As seen in Figure 4, action is a large part of knowledge, and self gains a smaller portion. Knowledge and action play a large role in technology. Without action upon knowledge, the knowledge is rendered useless. As a result, knowledge can then be either physically acted upon or verbally passed between two people. Self plays a smaller role in knowledge because self-actualization within technology is not as prevalent as say a nurse caring for the ill would feel about ones self. Finally, self and action integrate slightly because actions through technological knowledge bring only a small part of self-accomplishment (Barnett, 2001).

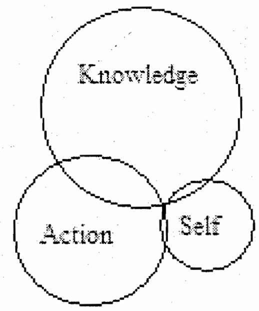

Figure 4. Curriculum: Technology schema

According to Dr. R. Thomas Wright (McCade, 1995), in order to develop a technology education curriculum, a five step process must be followed. Those five steps are:

1. Agreeing upon a philosophical base
2. Curriculum development
3. Teacher in-service
4. Test curriculum
5. Redesigning the curriculum

Agreeing upon a philosophical base begins the process by establishing a mission statement, defining technology education and establishing program goals. This gives the curriculum a start for development and builds a foundation. Curriculum development allows for identification of course goals, course content, methods for achieving goals and equipment/faculty needs. Completing this step builds upon the foundation while laying down definite goals and needs within the program. Teacher in-service provides teacher necessary programs and activities in order to understand how to achieve goals through curriculum delivery. Testing of the curriculum starts by implementation, then measuring the results through feedback measures, and finally comparing the measures to the goals. Lastly, redesigning the curriculum integrates all the previous steps by revising curriculum, if necessary, so that the mission and goals are achieved (McCade, 1995). Aspects of these steps will be utilized within this study to develop and analyze instructional modules.

Mager's Learning Objectives

In his book, Mager (1975) begins by stating that a learning objective is a description of a performance you want learners to be able to exhibit before you consider them competent. The objective describes an intended result or instruction, rather than the process of instruction itself. Further, he states that one must do two things for instruction to be successful. A person must first make certain there is a need for the instruction and then clarify the specific outcomes or objectives intended for the instruction to accomplish.

Mager (1975) specifies the difference between learning objectives and learning processes/procedures as: a learning objective is a statement describing an instructional outcome as opposed to describing results and the means of achieving those results. Describing outcomes rather than results is an important aspect of this study. When students complete a course using the results of this study, they should be able to perform what the learning objectives state.

Mager (1975) states learning objectives, sometimes referred to as instructional objectives, are used in this study for three main reasons. He adds that learning objectives are important because they provide a sound basis for the selection or designing of instructional content and procedures. This gives a starting point for the decision of where one wants to go. If you do not know where you want to go then it becomes hard to choose the means to get there.

If the purpose of this study is to infuse EDM into an undergraduate curriculum then there must be a way of achieving that, which is to develop comprehensive learning objectives for the creation of an instructional module. Secondly, it is important to evaluate or assess the success of the instruction. This can be accomplished through testing or evaluations, intended to decide how well the instruction teaches the objectives. Finally, organizing the students' own efforts and activities for the accomplishment of the instructional intents is a reason learning objectives are the focus of this study. Mager (1975) states that research shows if a student has clear objectives he/she will be better able to prepare themselves to learn what is necessary to meet the objectives.

In Mager's (1975) book, he describes three characteristics of learning objectives, which will be used as the basis in developing learning objectives of this study. They are:

1. Performance – An objective always says what a learner is expected to be able to do.
2. Conditions – An objective always describes the important conditions (if any) under which the performance is to occur.
3. Criterion – Wherever possible, an objective describes the criterion of acceptable performance by describing how well the learner must perform in order to be considered acceptable.

EDM Instructional Module Development

EDM is considered a nontraditional machining process (NTM). Through research and engineering, EDM is becoming increasingly useful, making the understanding of this process important at the undergraduate and even graduate level programs. In industry, it is common for an engineer to design a part, and then write the required machining techniques and processes required for the manufacturing of the part. If the engineer is without knowledge of NTM tools and methods, particularly EDM, they are essentially less efficient than the knowledgeable engineer.

Problems exist today in programs that educate these types of engineers because there is a lack of instructional modules to teach these particular processes. While traditional machining is generally easier to learn and apply, its over-use in teaching imposes on time spent educating NTM methods. A study done in 2005 by Yao, Cheng, Rajurkar, Kovacevic, Feiner, and Zhang counteracts this problem by not only providing education about the fundamentals of EDM, but also familiarizing students with this state of the art technology. The objectives of the Yao et al. (2005) study were:

1. To develop educational material that incorporates recent research results in NTM processes and systems into upper level undergraduate and introductory graduate level curricula.
2. To establish a model for effective and efficient learning of multi-disciplinary subjects.
3. To prepare a new generation of engineers with analytic background knowledge and process design/optimization skills in NTM.

During the study, three levels of modules were developed: introductory, intermediate and advanced. The introductory level covers most basic phenomena, mechanisms and theories. The intermediate level includes important phenomena, mechanisms and theories geared toward upper-level undergraduate and first level graduate students. Finally, the advanced level includes relatively special phenomena, mechanisms and relatively more advanced theories/analytical tools that primarily target graduate students and researchers. Within the EDM module, topics covered include types of EDM processes, surface integrity, process parameters, and energy states and mediums.

This study divided EDM into six categories, which will be the basis for this study. These categories are the history and evolution, theories of material removal, the process mechanism, pulses, dielectric fluids for EDM, types of processes including: die-sinking, wire and micro EDM. These categories will be the areas from which the learning objectives necessary to develop an instructional module are derived.

Delphi Study Techniques and Processes

The Delphi technique was brought about in the 1950's by the Rand Corporation as a research method in order to reach consensus from a panel of experts. Brown, Cochran and Dalkey (1969) define it as a technique designed to gather a group response compiled of elicit opinions.

They go on to describe how the technique utilizes questionnaires in order to avoid direct confrontation and debate. This technique needs to be carefully planned, anonymous between participants and of orderly fashion. Helmer (1966) further describes the technique as eliminating committee activity, thus eliminating influence related to certain psychological factors such as specious persuasion, unwillingness to abandon publicly expressed opinions and the bandwagon effect of majority opinion. The technique will also prevent shyness and unwillingness to express ones' opinion in the presence of virtual strangers.

Reeves and Jauch (1978) reported that a large amount of time is commonly devoted to curriculum development in colleges and universities. This large amount of time and uncertainty is commonly a result of curriculum designers disagreeing about curriculum content. These disagreements are commonly necessary although unless structured, they might be wasteful. The Delphi technique allows disagreement, but avoids face-to-face confrontation and allows a moderator (experimenter) to analyze these disagreements for a common ground alternative.

Turoff (1970) and Reeves and Jauch (1978) mentioned possible objectives of a Delphi study as:

1. To determine or develop a range of possible alternatives
2. To explore or expose underlying assumptions or information leading to differing judgments
3. To seek out information that may generate a consensus of judgment on the part of the respondent group
4. To correlate informed judgments on a topic spanning a wide range of disciplines
5. To educate the respondent group as to the diverse and interrelated aspects of the topic

Beach (1981) describes the Delphi technique as being "One of the most promising tools available to help educators plan for the future" (p. 229). Beach continues by stating, "The Delphi is also helpful in getting people to think in more complex ways than usual, particularly in regard to education" (p. 229).

The Delphi method has become important while slowly infusing into higher education, as reported by Judd (1972). Judd characterizes the Delphi method as having anonymity of response, multiple iterations, convergence of the distribution of answers and a statistical group response (median, interquartile range) preserving an intact distribution that may still remain wide. He also lists five major uses of Delphi in higher education (p.35):

1. Cost effectiveness
2. Cost-benefit analysis
3. Curriculum and campus planning
4. College, university wide and statewide educational goals and objectives
5. Consensus on rating scales
6. Values and other evaluation elements and generalized educational goals and objectives for the future

Summary

The aims of reviewing other research were as follows: (a) to understand what processes and principles EDM involves; (b) what types of EDM are used in industry as well as how they are used and have advanced; (c) an understanding of Bortz's learning module and how it relates to learning objectives; (d) the three components of technology based curriculum development; (e) how Mager develops useful learning objectives; (f) EDM instructional module development; and (g) the techniques and procedures of the Delphi method.

Before this study could begin, a basic understanding of EDM must be gained, including the uses and advancements seen in industrial applications. Furthermore, Bortz's learning module is an increasing useful tool for testing the acquisition of knowledge in a classroom setting. This module is suggested when using learning objectives to create an EDM course. It is also to understand the relationship between self, knowledge and action in relation to technology-based curriculum. It is very important to understand how learning objectives should be developed. In his book, Mager defines the steps and parts of an effective learning objective. A model commonly referred to throughout this study is the EDM instructional module created by Yao et al. (2005). This module, although not based on learning objectives, is a valuable tool when creating the basis for a learning module. Finally, it was necessary to review the techniques and procedures for a Delphi method of study. The Delphi method was utilized during the study as a key resource to create complete, unbiased learning objectives.

The main purpose of this study was to create learning objectives that can be later used to develop an EDM module for undergraduate students, giving them the opportunity to gain knowledge and skills of EDM processes and procedures. The review of literature created a foundation for the study to build and advance understanding of EDM.

CHAPTER 3

METHODOLOGY

EDM is a widely used machining method in today's industry. This is because of its versatility, precision and ability to create specialized workpieces, previously impossible by other machining methods. Undergraduates preparing for industry would benefit from an understanding of the processes and procedures.

This study focused on learning objective development for six categories of EDM processes and procedures. A panel of experts was utilized from academia and industry nominated by a group of individuals from industry, research institutions, professional organizations, and academia.

The study gathered learning objectives derived from the panel of experts. Once the information constituents of the study were gathered, grouped and evaluated, they were analyzed in order to derive the most important learning objectives for creation of a comprehensive instructional module for undergraduate studies.

Delphi Method

The idea of this study was to create learning objectives using the Delphi technique through a panel of experts. Helmer (1966) describes this approach as a systematic solicitation and collation of expert opinions. He further describes the method as applicable when policies and plans must be based on informed judgment.

Participants

The first participants in this study nominated experts in the field of EDM. Nominators, all part of a large engineering technology listserv, were sent a letter via electronic mail (Appendix A) and asked to nominate experts based on the criteria listed below. These nominators were picked to create a diverse yet homogenous mix in the realm of EDM. Each nominator was asked to nominate five people from each industry and academia. Criteria for the experts were as follows:

1. Industry
    1. 15 years experience closely working with Electrical Discharge Machining
    2. Has experience with design and manufacture related to Electrical Discharge Machining
    3. Resides within the United States of America
2. Academia
    1. Graduate degree from a technology program
    2. 10 years or more working in academia (technology related)
    3. Resides within the United States of America

An engineering technology listserv was used as a start for nominations and when suggested by responding nominators, others were contacted for nominations. As of March 23, 2007 the listserv consisted of 3806 members representing 870 institutions from 2 year to 4 year colleges, organizations, corporations and government agencies. Others contacted were Poco Graphite, Sodick EDM and Charmille EDM, but no response was received.

Design

Once a panel of experts was compiled, each expert was contacted by phone or electronic mail and asked to participate in the study. Once confirmations were made, the final panel of experts was sent round one via electronic mail on April 2, 2007.

Round one (Appendix B and C) asked each expert to write no less than three, but no more than five learning objectives for six EDM categories derived from Yao et al's. (2005) National Science Foundation funded study involving EDM curricula development. The EDM categories include the history and evolution, theories of material removal, the process mechanism, pulses, dielectric fluids and types of processes including die-sinking, wire and micro EDM.

These learning objectives should represent the most important elements of EDM under each category. These learning objectives should prepare students to work within industry. These learning objectives will be created based on Mager's theory of learning objectives. According to Mager (1975) useful objectives should include performance (what the learner is able to do), conditions (important conditions under which the performance is expected to occur) and criterion (the quality or level of performance considered acceptable).

Each expert had one week, although some took longer, to derive the learning objectives and send their results back via electronic mail. A follow-up letter (Appendix D) was sent April 10, 2007 to remind the experts of the study and offer an opportunity to solve any problems or answer any questions about round one. After receiving round one's response from the experts a list of learning objectives was compiled. Learning objectives that were similar between two or more experts were combined.

Round two (Appendix E and F) asked each expert to examine the 44 compiled learning objectives and rank them using a Likert scale. The experts had a choice between extremely unnecessary (E U), very unnecessary (V U), unnecessary (U), necessary (N), very necessary (V N) and extremely necessary (E N). Each expert had one week, although some took longer, to fill out the study and return it via electronic mail. A follow-up letter (Appendix G) was sent out after one week as a reminder of round two and an opportunity to solve problems or answer questions. After receiving the studies back from the experts a consensus was discovered (Appendix H).

Round three was not necessary based on the results of round two.

Summary

The objective of this research study was to develop comprehensive learning objectives that support undergraduates' acquisition of knowledge and skills of the EDM processes and procedures for future creation of a comprehensive learning module. The module will incorporate the learning objectives derived from this study to provide the undergraduate students the opportunity to gain both knowledge and skills relating to EDM processes and procedures.

The study will use participants nominated from academia and industry. These participants must be willing and meet the criteria given previously. The participants were sent a series of rounds and asked to create learning objectives they, as individuals, felt are important to EDM. They then were asked to rank learning objectives from a compiled list on a Likert scale based on their opinion of necessity. From that, the necessary learning objectives needed for undergraduate EDM studies will be derived. This process follows the basic outline of a Delphi style study.

CHAPTER 4

RESULTS

The purpose of this Delphi study was to develop comprehensive learning objectives that support undergraduates' acquisition of knowledge and skills of the EDM processes and procedures. These learning objectives were derived using the Delphi study technique. The development of these learning objectives will provide valuable information in the development of curriculum in the teaching of undergraduates.

The study addressed the following research question: What electrical discharge machining learning objectives have practical significance for graduates preparing for industry?

This chapter is divided into four sections: the Delphi methodology, description of the panel members, panel's opinions, and summary of the data. Findings regarding this research question will be addressed based on the opinions provided through the panel discussions and evaluation process.

The Delphi Methodology

The Delphi technique was first introduced in the 1950's as a research tool. The main purpose of the Delphi was to reach consensus from a panel of experts. Brown, Cochran and Dalkey (1969) describe the method as a way to gain a group response of opinions while avoiding direct confrontation and debate. The technique uses a series of questionnaires and must be organized and carried out in an orderly fashion. As described by Helmer (1966) the method eliminates committee activity, thus eliminating influence related to certain psychological factors such as specious persuasion, unwillingness to abandon publicly expressed opinions and the bandwagon effect of majority opinion.

Description of the Panel Members

A panel of six experts was derived from nominations. Eventually, three could not participate throughout the entire study. These nominations were gathered from an electronic mail sent on a listserv of approximately 3,800 members from industrial and engineering technology.

All of the experts were chosen based on their experience within industry and academia. For the purpose of simplicity, the experts will be referred to as expert one, two or three. Expert one has five years experience with design and manufacturing of wire EDM, along with a combined total of 13 years teaching and researching micro-manufacturing including EDM. Expert two has four years experience designing and developing EDM, Wire EDM, ECM and ECG machine tools and their applications for customers. Expert two also has 14 years in academia involving mechanical and manufacturing engineering. Expert three brings over 28 years of EDM experience to the study. Expert three has written hundreds of articles and publications while serving on many technology related boards and committees.

The Panel's Opinions

The following results discussed are the opinions gathered from the expert panel as to what learning objectives are important to undergraduate studies in EDM. The gathering of learning objectives was completed during two rounds of a Delphi method study. Experts were contacted after being nominated by members of a listserv. If the experts agreed to participate in the study, then round one was distributed to that expert.

Round one (Appendix B and C) was sent to each expert and asked for learning objectives related to six categories of EDM including: the history and evolution, theories of material removal, the process mechanism, pulses, dielectric fluids and types of processes including die-sinking, wire and micro EDM. Two experts did not respond and one had to drop due to time constraints. Three experts responded and their learning objectives were compiled to create round two (Appendix H).

Round two was then sent out and the three remaining experts responded. Round two consisted of using a Likert scale type procedure. This round used choices of extremely unnecessary (E U), very unnecessary (V U), unnecessary (U), necessary (N), very necessary (V N) and extremely necessary (E N) for each of the 44 learning objectives. After the results of round two were compiled, it was determined unnecessary to create a round three instrument.

As shown in Table 1 the majority (highlighted in bold) of the history and evolution learning objectives relating to EDM are necessary for undergraduate studies. Although, knowledge of early research and development including: World War II, The Lazerankos, Americans/Ex-cello, Elox, Swiss/AGIE, Charmilles, Japanese/IJR Research, Japax, Sodick, Makino was found to be unnecessary by the majority of the expert panel. Explaining historic evolution of non-traditional material removal processes including a rough timeframe for each was found to be necessary. While, explaining industrial applications of non-traditional material removal processes was found to be very necessary. Explaining basic requirements, development and influence of computer control in non-traditional material removal processes was found to be necessary. Explaining adaptive control and present use of it in non-traditional material removal processes was found to be necessary by the median. Finally, explaining present development trends in adaptive control for non-traditional material removal processes is necessary.

Table 1

Compilation of Round Two Responses: Category I

Category I. - The History and Evolution	EU	VU	U	N	VN	EN
o Knowledge of early research and development including: World War II, The Lazerankos, Americans/Ex-cello, Elox, Swiss/AGIE, Charmilles, Japanese/IJR Research, Japax, Sodick, Makino			**OI**	X		
o Explain historic evolution of non-traditional material removal processes including a rough timeframe for each			O	**IX**		
o Explain industrial applications of non-traditional material removal processes				I	**O**	X
o Explain basic requirements, development and influence of computer control in non-traditional material removal processes				**XO**	I	
o Explain adaptive control and present use of it in non-traditional material removal processes			X	**O**	I	
o Explain present development trends in adaptive control for non-traditional material removal processes			I	**XO**		

In Table 2, the majority of theories of material removal are very necessary learning objectives in undergraduate studies. Naming principle types of material removal mechanisms including: Electro-chemical (ECM), Thermo-mechanical, Thermo-electric, Electro-mechanical is a necessary learning objective. Estimating the material removal rate was found to be very necessary. Also, found to be very necessary, understanding the mechanism, effect of polarity on parameters and apply to wire, die sinking, and micro EDM. Explaining physical principles underlying each type of material removal mechanism is very necessary. Explaining drawbacks of each theory is very necessary. The only learning objective in this category that was found to be unnecessary was naming application of each theory as utilized in commercial software. Finally, explaining principal theories used to describe and quantify each type of material removal mechanisms was found to be necessary.

Table 2

Compilation of Round Two Responses: Category II

Category II. - Theories of Material Removal	EU	VU	U	N	VN	EN
○ Name principal types of material removal mechanisms including: Electro-chemical (ECM), Thermo-mechanical, Thermo-electric, Electro-mechanical				**OI**	X	
○ Estimate the material removal rate					**XOI**	
○ Understand the mechanism. Effect of polarity on parameters and apply to wire, die sinking, and micro EDM					**XO**	I
○ Explain physical principles underlying each type of material removal mechanism					**OI**	X
○ Explain drawbacks of each theory				X	**OI**	
○ Name applications of each theory as utilized in commercial software			**XOI**			
○ Explain principal theories used to describe and quantify each type of material removal mechanisms		I		**O**	X	

Table 3 shows many of the learning objectives regarding the process mechanism to be very necessary for undergraduate curriculum. EDM theory including voltage, amperage, ionization, vapor pressure, dielectrics, electrode materials, workpiece materials, and etcetera is a very necessary learning objective. As well as, wire selection including brass, simple coated, diffusion annealed, moly, and tungsten.

Table 3

Compilation of Round Two Responses: Category III

Category III. - The Process Mechanism	EU	VU	U	N	VN	EN
o EDM theory including: voltage, amperage, ionization, vapor pressure, dielectrics, electrode materials, workpiece materials, etc.					**OI**	X
o Wire selection including: brass, simple coated, diffusion annealed, moly, tungsten					**OI**	X
o Electrode selection including: metallic/graphite					I	**XO**
o Know the dominant parameters					**OI**	X
o Explain process mechanism for: EDM, WEDM, ECM, ECG, ECDeburring, small holes drilling with EDM, micro EDM, precision WEDM			I		**O**	X
o Explain limitations for each process from perspective of materials: workpiece, tool, environment (fluids)				O	**I**	X
o Explain technological, economic and environmental limitations to each process				**OI**		X
o Explain industrial applications of each process				O	**I**	X
o Explain degree of precision in generation of: shape, surface quality, subsurface damage, chemical composition change for each process				**OI**		X

Found to be extremely necessary is electrode selection including: metallic/graphite. While knowing the dominant parameter is very necessary. Explaining process mechanism for: EDM, WEDM, ECM, ECG, ECDeburring, small holes drilling with EDM, micro EDM, precision WEDM is too, very necessary. In the same Likert scale ranking of very necessary is explaining limitations for each process from perspective of materials: workpiece, tool, environment (fluids). Explaining technological, economic and environmental limitations to each process was found to be necessary. Explaining industrial applications of each process is a very necessary learning objective. Finally, explaining the degree of precision in generation of: shape, surface quality, subsurface damage, chemical composition change for each process was found to be necessary.

As shown in Table 4, the majority of the learning objectives relating to pulses are necessary to undergraduate curriculum. Knowledge and ability to use RC/DC/AC generators was found to be an unnecessary learning objective. Knowledge of electrical arcs and preventions of shorts is necessary. Knowledge and application of typical ranges for common material (e.g. steel) is also necessary. The ability to choose appropriate polarity, pulse type and generator type given technological parameters of the process, machine tool used, tools, materials machined, electrode material, geometric features of machined shape, and duty cycle on material removal rate was found to be necessary.

Table 4

Compilation of Round Two Responses: Category IV

Category IV. – Pulses	EU	VU	U	N	VN	EN
○ Knowledge and be able to use RC/DC/AC generators			**XO**		I	
○ Knowledge of electrical arcs and preventions of shorts				**XOI**		
○ Knowledge and application of typical ranges for common material (e.g. steel)			I	**O**		X
○ Choose appropriate polarity, pulse type and generator type given: technological parameters of the process, machine tool used, tools, materials machined, electrode material, geometric features of machined shape, duty cycle on material removal rate			I	**O**	X	
○ Explain general influence of: on time, off time, shape of pulse and open gap/working voltage/current control in the gap, on outcomes of EDM process (spark gap size, surface generated, electrode wear/build-up/breakage, possibility of generating sharp features, possibility of generating small features)					**OI**	X
○ Choose appropriate pulse settings for given technological task: material machined, part size, surface roughness desired, geometric features of machined shape electrode used, tolerance of subsurface stresses and metallurgical change		I			**XO**	

Explaining general influence of: on time, off time, shape of pulse and open gap/working voltage/current control in the gap, on outcomes of EDM process (spark gap size, surface generated, electrode wear/build-up/breakage, possibility of generating sharp features, possibility of generating small features) is very necessary. Similarly, the ability to choose appropriate pulse settings for given technological task: material machined, part size, surface roughness desired, geometric features of machined shape electrode used, tolerance of subsurface stresses and metallurgical change was found to be very necessary.

Table 5

Compilation of Round Two Responses: Category V

Category V. - Dielectric Fluids for EDM	EU	VU	U	N	VN	EN
○ Name basic types of fluids used in all types machining in EDM, WEDM, ECM, ECG, ECDeburring, small holes drilling with EDM, micro EDM, precision WEDM		I		**O**		X
○ Explain fluids' advantages, disadvantages, and cost of initial purchase and maintenance			I	**O**	X	
○ Understand mechanism of ionization				X	**OI**	
○ Dielectric type and effects upon workpiece surface finish, surface integrity				X	**O**	I
○ Properties of water dielectrics				**OI**	X	
○ Dielectric type and effects upon workpiece chemistry and metallurgy					**XO**	I
○ Types and properties of oil dielectrics – paraffinic, hydrocarbon, napthenic, aromatic and synthetic, Dielectric additives				I	**X**	O

Dielectric fluids for EDM, Table 5, are shown to be either necessary or very necessary. Naming basic types of fluids used in all types machining in EDM, WEDM, ECM, ECG, ECDeburring, small holes drilling with EDM, micro EDM, precision WEDM is necessary, as well as explaining fluids' advantages, disadvantages, and cost of initial purchase and maintenance. Understanding the mechanism of ionization was found to be very necessary as well as dielectric type and effects upon workpiece surface finish, surface integrity. Properties of water dielectrics are necessary. Dielectric type and effects upon workpiece chemistry and metallurgy was found to be very necessary. Finally, types and properties of oil dielectrics – paraffinic, hydrocarbon, napthenic, aromatic and synthetic, Dielectric additives is very necessary.

Table 6 represents types of processes including die-sinking, wire and micro EDM. The majority of the learning objectives in this category were found to be necessary. Sinker design, including C-frame, compound table, and gantry was found to be unnecessary. While, sinker generator, including: RC/DC/AC, avg. current, peak current, capacitors, carbide circuitry, fine finish circuitry, effects of dielectric additives, and etcetera was found to be necessary. Wire design, including C-frame, compound table, and gantry was similarly found to be unnecessary as well as wire generator including DC/AC, anti-electrolysis circuitry, carbide circuitry, fine finish circuitry, adaptive control, effects of dielectrics and additives. Machining size/shape constraints were selected as being an extremely necessary learning objective. Differentiating the types and limitation of each process was found to be very necessary.

Explaining advantages, disadvantages and industrial applications of: EDM, WEDM, ECM, ECG, ECDeburring, ECPolishing, small holes drilling with EDM, micro EDM, and precision/micro WEDM is necessary. Likewise, explaining present development trends (industry and academia) in: EDM, WEDM, ECM, ECG, ECDeburring, ECPolishing, small holes drilling with EDM, micro EDM, precision/micro WEDM; laser machining, water jet cutting, and abrasive jet cutting is necessary.

Table 6

Compilation of Round Two Responses: Category VI

Category VI. - Types of Processes Including: Die-Sinking, Wire and Micro EDM	EU	VU	U	N	VN	EN
Sinker design including: C-frame, compound table, gantry		O	**I**	X		
Sinker generator including: RC/DC/AC, avg. current, peak current, capacitors, carbide circuitry, fine finish circuitry, effects of dielectric additives, etc.		O		**XI**		
Wire design including: C-frame, compound table, gantry		O	**I**	X		
Wire generator including: DC/AC, anti-electrolysis circuitry, carbide circuitry, fine finish circuitry, adaptive control, effects of dielectrics and additives		O	**X**		I	
Machining size/shape constraints		O				**XI**
Differentiate the types and limitation of each		O			**X**	I
Explain advantages, disadvantages and industrial applications of: EDM, WEDM, ECM, ECG, ECDeburring, ECPolishing, small holes drilling with EDM, micro EDM, precision/micro WEDM				**OI**		X
Explain present development trends (industry and academia) in: EDM, WEDM, ECM, ECG, ECDeburring, ECPolishing, small holes drilling with EDM, micro EDM, precision/micro WEDM; laser machining, water jet cutting, abrasive jet cutting				**OI**	X	
Explain advantages, disadvantages and industrial applications of: laser machining, water jet cutting, and abrasive jet cutting		O		**I**		X

Summary

Responses to round one resulted in 60 learning objectives. After careful examination and combination of like learning objectives, 44 learning objectives in the six different categories were derived. These were then used for the creation of round two.

Round two was then sent out and panel members chose the necessity of each objective using a Likert scale. The Likert scale choices consisted of extremely unnecessary (E U), very unnecessary (V U), unnecessary (U), necessary (N), very necessary (V N) and extremely necessary (E N). An even number of choices were used in order to avoid a neutral choice and six were necessary because it was decided that four did not provide a broad enough range of necessity . Round three was never created due to the responses of round two.

CHAPTER 5

DISCUSSION AND CONCLUSIONS

Electrical discharge machining (EDM) is a highly precise machining method that utilizes electrical pulses to erode and/or vaporize metal. EDM has become very popular, not only because of its extreme precision, but because of the ability to machine carbides and tool steels without deformation to the workpiece (Brink, 1999). Two types of EDM processes: die-sinking and wire cutting are available and each has their respective uses. Die-sinking uses an electrode which is fed into the workpiece creating an inverted replica (Charmilles US, 2004). This study focused on creating learning objectives divided into six categories of EDM procedures and principles. After a panel of nominated experts was created from academia and industry, round one of the Delphi study was electronically mailed to those involved. This round asked that each expert create three to five learning objectives for each of the six categories. These responses where then used to create round two in which the experts where asked to choose the necessity of each learning objective on a six point Likert scale. The final learning objectives can then be used to create a comprehensive instructional module.

Research Question

The purpose of this study was to answer the following question: What electrical discharge machining learning objectives have practical significance for college students preparing for industry?

By using the Delphi method, this study was able to compile a complete list of learning objectives necessary for an undergraduate level EDM course. If these learning objectives are met, it is the feeling of the researcher that an undergraduate will be prepared to work within industry relating to EDM.

Appropriate Learning Objectives

The researcher was able to construct a comprehensive list of learning objectives necessary for an undergraduate level course focusing on electrical discharge machining. A list of learning objectives was found to be as follows:

The History and Evolution

- Given a pencil, paper, and a list of leading factors associated with significant EDM processes, the student will within 10 minutes be able to explain in writing the industrial application of non-traditional material removal processes associated with EDM.

Theories of Material Removal

- In a classroom, given a calculator, pencil, paper, material specification and the material rate removal formula, the student will calculate within 15 minutes a 98% accurate material removal rate for each of the following EDM process: wire, die-sinking and micro.
- Given a pencil and paper, the student will within 10 minutes and according to standard EDM practices, be able to explain in writing the effect (the mechanism) of polarity on the parameters when applied to wire, die-sinking and micro EDM.
- Given a pencil and paper, the student will within 10 minutes and according to standard EDM practices, be able to explain in writing the physical principles underlying each type of material removal mechanism associated with wire, die-sinking and micro EDM.

- Given a pencil and paper, the student will within 10 minutes and according to standard EDM practices, be able to explain in writing the drawbacks associated with wire, die-sinking and micro EDM.

The Process Mechanism

- Given a pencil and paper, the student will within 10 minutes and according to standard EDM practices, be able to explain in writing the process mechanisms associated with wire, die-sinking, and micro EDM, including: voltage, amperage, ionization, vapor pressure, dielectrics, electrode materials, workpiece materials, etc.
- Given a pencil, paper, specific material specification and/or type of EDM process, the student will within 10 minutes and according to standard EDM practices, be able to explain in writing the methods and reasons of wire selection with the following wire types; brass, simple coated, diffusion annealed, moly, and tungsten.
- Given a pencil and paper, the student will within 10 minutes and according to standard EDM practices, be able to explain in writing how electrode selection, including metallic/graphite, is determined.
- Given a pencil and paper, the student will within 10 minutes and according to standard EDM practices, be able to explain in writing the dominant parameters associated with the process mechanism.
- Given a pencil, paper, EDM, WEDM, ECM, ECG, ECDeburring, small holes drilling with EDM, micro EDM, and precision WEDM, the student will within 60

minutes and according to standard EDM practices, be able to diagram and explain in writing each of the processes mechanism.

- Given a pencil, paper and a specific process, the student will within 20 minutes and according to standard EDM practices, be able to explain in writing the limitations for each process from the perspective of the materials (workpiece, tool, and environment (fluids)).
- Given a pencil, paper and a specific process, the student will within 20 minutes and according to standard EDM practices, be able to explain in writing the industrial applications of each process.

Pulses

- Given a pencil, paper and the specific outcomes of an EDM (spark gap size, surface generated, electrode wear/build-up/breakage, possibility of generating sharp features, possibility of generating small features), the student will within 20 minutes and according to standard EDM practices, be able to explain in writing the general influence of on time, off time, shape of pulse, and open gap/work voltage/current control in the gap on these.
- Given a pencil, paper and an EDM task (material machined, part size, surface roughness desired, geometric features of machined shape electrode used, tolerance of subsurface stress, and metallurgical change), the student will within 5 minutes and according to standard EDM practices, be able to choose the appropriate pulse settings.

Types of Processes Including: Die-Sinking, Wire and Micro EDM

- Given a specific process (die-sinking, wire, and micro EDM), the student will within 5 minutes and according to standard EDM practices be able to define in writing the mechanism of ionization.
- Given a pencil, paper, and a specific process (die-sinking, wire, and micro EDM), the student will within 10 minutes and according to standard EDM practices be able to list the characteristics involving dielectric type and be able to describe the effects upon workpiece surface finish and surface integrity.
- Given a pencil, paper, and specific process (die-sinking, wire, and micro EDM), the student will within 10 minutes and according to standard EDM practices be able to list the characteristics involving dielectric type and be able to describe the effects upon workpiece chemistry and metallurgy.
- Given a pencil, paper, and specific oil, the student will within 20 minutes and according to standard EDM practices be able to list different types of oil and their properties of oil dielectrics (paraffinic, hydrocarbon, napthenic, aromatic, and synthetic).

Dielectric Fluids for EDM

- Given a pencil, paper, and a specific dielectric fluid, the student will within 20 minutes and according to standard EDM practices be able to describe in writing the machining size/shape constraints and considerations associated with specific dielectric fluid.

- Given a pencil, paper a specific fluid, the student will within 20 minutes and according to standard EDM practices be able to describe in writing the characteristics and limitations of each fluid.

This list consists of 20 learning objectives found by the panel of experts to be either very necessary or extremely necessary for undergraduate curriculum. There are 18 additional learning objectives found to be necessary, but were excluded. These learning objectives are still necessary for undergraduate studies. However, it is the opinion of the researcher that if all 38 learning objectives are incorporated they should be divided into two EDM courses.

It is felt that one course would have too many learning objectives if those were included. It is also the researcher's opinion that the list formed using the Delphi method is a very comprehensive representation in order to prepare students for industry applications. It can be seen that little emphasis is focused on the history, but more on the process and material removal involved in EDM. This would prepare students with an understanding of the EDM process, especially material removal.

These findings are a step in the process of developing a complete instructional module for EDM. In order to create a successful module, learning objectives must be created. This is so that the course has objectives for students to learn and there is a way to evaluate what has been learned at the conclusion of a course. This study can be taken further by incorporating the learning objectives that were found by experts to be necessary for undergraduate EDM studies. This study only used very necessary and extremely necessary learning objectives.

It is thought that the Delphi method of study was a key tool in the collection and assessment of necessary learning objectives for an undergraduate level study of EDM. The method allowed the researcher to receive responses from both academia and industrial personnel. If possible, the method might be more effective if more experts are used. Although using only a few experts is effective, generating more learning objectives is possible with the addition of experts. Likewise, there is a possibility of three rounds in a Delphi type study with more experts. Two rounds worked well for this type of study, lessoning the burden on the expert participants. This method is also recommended to create learning objectives not only for other machines such as lathes or mills, but to be used in other technology genre.

Recommendations

Several recommendations can be made for further investigations of EDM. Like with most research, many more studies can be performed with the information from the initial study.

Mager's thoughts and recommendations were that the creation of learning objectives should represent the characteristic under study. The learning objectives in this study do not follow what Mager's recommendations precisely, but they do represent a starting point for the creation of learning objectives. As a result, this study created learning objectives for an EDM undergraduate level course, but the learning objectives do not completely represent Mager's three learning objective characteristics.

EDM technology continually improves, making EDM more important in industry. As a result, this machining method needs to be taught to future leaders and technologists in industry. Studies pertaining to the education of EDM will allow the gap between education and industry to be lessoned.

Based on the findings and conclusions of this research and study, the following recommendations for further investigations can be made.

1. Use the results of this study to create learning objectives closely representing Mager's three characteristics for learning objectives.
2. Use learning objectives found in this study to create instructional modules for EDM.
3. Research the effectiveness of differing EDM instructional modules for information retention. (i.e. Computer delivered information versus instructor delivered information)
4. Derive learning objectives using the Delphi method for other machinery used in an undergraduate technology program.

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APPENDICES

Appendix A

Letter for Nominations

Dear Academia and Industry Personnel,

With today's fast paced competitive manufacturing industrial challenges it benefits to hire both well educated and rounded individuals. These individuals gain this advantage from the education received during their academic careers. In many cases the more manufacturing experiences they are exposed to during their education, the greater benefit they can be in industry. Every industrial professional wants employees to be a valuable asset with the skills expected to perform the assigned duties and responsibilities.

At Eastern Illinois University's School of Technology the aim is to prepare students for careers in different technological fields. The program strives to stay current with industrial advances and offers a comprehensive curriculum to their students. Currently the program lacks a curriculum for Electrical Discharge Machining (EDM). EDM is a nontraditional machining process that has become prevalent in industry over the past two decades. The question that must be asked then, do we teach EDM as part of the curriculum and if so what should be the learning objectives?

As a result here at EIU we are doing research on creating learning objectives for an EDM instructional module. These learning objectives would be the bases for creating an individual instructional module for undergraduate studies. We have chosen to do the study via the Delphi technique. A panel of experts in the field of EDM is essential to complete the study. This is where your help is needed in nominating EDM experts within industry or academia areas. If you know someone (self-nominations are acceptable) whom meets all of the following criteria within industry or academia we would like to ask you today to respond with their contact information. Your help is greatly appreciated for the furthering of this study and the enhancement of the quality of undergraduate studies in the future.

Criteria

1. Industry
    1. 15 years experience closely working with Electrical Discharge Machining
    2. Has experience with design and manufacture related to Electrical Discharge Machining
    3. Resides within the United States of America
2. Academia
    1. Graduate degree from a technology program
    2. 10 years or more working in academia (technology related)
    3. Resides within the United States of America

Thank you for your time,

Aaron Harmon
Production Research Assistant
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David W. Melton
Assistant Professor
Eastern Illinois University
dwmelton@eiu.edu

Appendix B

Expert Invitation Letter

Dear So and So,

With today's fast paced competitive manufacturing industry it benefits to hire both well educated and rounded individuals. These individuals gain this advantage from the education received during their academic careers. In many cases the more manufacturing experiences they are exposed to during their education, the greater benefit they can be in industry. Every industrial professional wants employees to be a valuable asset with the skills expected to perform the assigned duties and responsibilities.

Eastern Illinois University's School of Technology is aimed at preparing students for the technology field. The program strives to stay current with industry advances and offers a comprehensive curriculum to their students. Currently the program lacks a curriculum for Electrical Discharge Machining. Electrical Discharge Machining is a specialized machining process and its use is becoming more prevalent in industry. As a result it is becoming more important for students to learn this process to become a greater asset in industry.

As a result I have decided to base my thesis research on creating learning objectives useful in industry for electrical discharge machining. These learning objectives can then be the bases for creating individual instructional modules for undergraduate studies. I have chosen to do the study via the Delphi technique. A panel of nominators from academia, industry and organizations were summoned to nominate experts in the field of electrical discharge machining. Today, I am asking you to participate in the studies first round (attached) as part of the panel of experts.

The study will consist of three rounds. Round one will ask each expert to provide needed learning objectives for six categories of EDM. The second round will require the panel to rate different learning objectives on a Likert scale. The third round will ask each expert to compare their rankings to a consensus of the panel. I suspect this study will only take a short amount of your time, while providing valuable information and increasing the success and impact of future graduates. Your participation and commitment to all three rounds is greatly appreciated.

Respectfully,

Aaron Harmon
Production Lab Assistant
Eastern Illinois University
(217) 276-8556
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Appendix C

Delphi Instrument – Round One

Below you will find six categories related to electrical discharge machining (EDM). For each category write a series of learning objective related to that particular area. More can be found about each category at http://www.unl.edu/nmrc/EDMresearch.htm. Remember to write the objectives based on Robert Mager's theory of learning objectives. Include performance (what the learner is able to do), conditions (important conditions under which the performance is expected to occur) and criterion (the quality or level of performance considered acceptable). Please write at least three, but no more than five for each category. When you are finished please electronically mail your response back within one week (April 9, 2007).
Example Objective: Shall be able to identify three types of electrode material and be able to solve for a desired surface finish within 50 microinches for each.

Category I. - The History and Evolution

1.
2.
3.
4.
5.

Category II. - Theories of Material Removal

1.
2.
3.
4.
5.

Category III. - The Process Mechanism

1.
2.

3.
4.
5.

Category IV. – Pulses

1.
2.
3.
4.
5.

Category V. - Dielectric Fluids for EDM

1.
2.
3.
4.
5.

Category VI. - Types of Processes Including: Die-Sinking, Wire and Micro EDM

1.
2.
3.

4.
5.

Appendix D

Follow-up Letter – Round One

Expert Panel Member,

I hope you have found time in the past week to develop learning objectives for electrical discharge machining. With a small panel of experts your participation is appreciated and very important to the furthering of this study. Please complete round one as soon as possible and return it for the development of round two. If you might have any questions please contact me.

Thank you,

Aaron Harmon
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Appendix E

Cover Letter - Round Two

Expert Panel Member,

Thank you for your response to round one of this Delphi study. Round two is attached and should only take a very short amount of your time although your response is very important to completion of this study. Thank you again for you time and please let me know if you have any questions.

Respectfully,

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Appendix F

Delphi Instrument – Round Two

Thank you for your valued response in round one. This round should be much quicker. All learning objectives from round one have been compiled to make a final list under each respective category. Like objectives were combined. Please rate each objective according to your opinion about its necessity within an undergraduate electrical discharge machining curriculum. When you are finished please electronically mail your response back within one week (May 4, 2007).

	Extremely Unnecessary	Very Unnecessary	Unnecessary	Necessary	Very Unnecessary	Extremely Necessary
Category I. - The History and Evolution						
o Knowledge of early research and development including: World War II, The Lazerankos, Americans/Ex-cello, Elox, Swiss/AGIE, Charmilles, Japanese/IJR Research, Japax, Sodick, Makino	___	___	___	___	___	___
o Explain historic evolution of non-traditional material removal processes including a rough timeframe for each	___	___	___	___	___	___
o Explain industrial applications of non-traditional material removal processes	___	___	___	___	___	___
o Explain basic requirements, development and influence of computer control in non-traditional material removal processes	___	___	___	___	___	___
o Explain adaptive control and present use of it in non-traditional material removal processes	___	___	___	___	___	___
o Explain present development trends in adaptive control for non-traditional material removal processes	___	___	___	___	___	___

Category II. - Theories of Material Removal	
o Name principal types of material removal mechanisms including: Electro-chemical (ECM), Thermo-mechanical, Thermo-electric, Electro-mechanical	___ ___ ___ ___ ___ ___
o Estimate the material removal rate	___ ___ ___ ___ ___ ___
o Understand the mechanism. Effect of polarity on parameters and apply to wire, die sinking, and micro EDM	___ ___ ___ ___ ___ ___
o Explain physical principles underlying each type of material removal mechanism	___ ___ ___ ___ ___ ___
o Explain drawbacks of each theory	___ ___ ___ ___ ___ ___
o Name applications of each theory as utilized in commercial software	___ ___ ___ ___ ___ ___
o Explain principal theories used to describe and quantify each type of material removal mechanisms	___ ___ ___ ___ ___ ___
Category III. - The Process Mechanism	
o EDM theory including: voltage, amperage, ionization, vapor pressure, dielectrics, electrode materials, workpiece materials, etc.	___ ___ ___ ___ ___ ___
o Wire selection including: brass, simple coated, diffusion annealed, moly, tungsten	___ ___ ___ ___ ___ ___
o Electrode selection including: metallic/graphite	___ ___ ___ ___ ___ ___
o Know the dominant parameters	___ ___ ___ ___ ___ ___
o Explain process mechanism for: EDM, WEDM, ECM, ECG, ECDeburring, small holes drilling with EDM, micro EDM, precision WEDM	___ ___ ___ ___ ___ ___

o Explain limitations for each process from perspective of materials: workpiece, tool, environment (fluids)	___ ___ ___ ___ ___ ___
o Explain technological, economic and environmental limitations to each process	___ ___ ___ ___ ___ ___
o Explain industrial applications of each process	___ ___ ___ ___ ___ ___
o Explain degree of precision in generation of: shape, surface quality, subsurface damage, chemical composition change for each process	___ ___ ___ ___ ___ ___
Category IV. – Pulses	
o Knowledge and be able to use RC/DC/AC generators	___ ___ ___ ___ ___ ___
o Knowledge of electrical arcs and preventions of shorts	___ ___ ___ ___ ___ ___
o Knowledge and application of typical ranges for common material (e.g. steel)	___ ___ ___ ___ ___ ___
o Choose appropriate polarity, pulse type and generator type given: technological parameters of the process, machine tool used, tools, materials machined, electrode material, geometric features of machined shape, duty cycle on material removal rate	___ ___ ___ ___ ___ ___
o Explain general influence of: on time, off time, shape of pulse and open gap/working voltage/current control in the gap, on outcomes of EDM process (spark gap size, surface generated, electrode wear/build-up/breakage, possibility of generating sharp features, possibility of generating small features)	___ ___ ___ ___ ___ ___
o Choose appropriate pulse settings for given technological task: material machined, part size, surface roughness desired, geometric features of machined shape electrode used, tolerance of subsurface stresses and metallurgical change	___ ___ ___ ___ ___ ___

Category V. - Dielectric Fluids for EDM	
o Name basic types of fluids used in all types machining in EDM, WEDM, ECM, ECG, ECDeburring, small holes drilling with EDM, micro EDM, precision WEDM	___ ___ ___ ___ ___ ___
o Explain fluids' advantages, disadvantages, and cost of initial purchase and maintenance	___ ___ ___ ___ ___ ___
o Understand mechanism of ionization	___ ___ ___ ___ ___ ___
o Dielectric type and effects upon workpiece surface finish, surface integrity	___ ___ ___ ___ ___ ___
o Properties of water dielectrics	___ ___ ___ ___ ___ ___
o Dielectric type and effects upon workpiece chemistry and metallurgy	___ ___ ___ ___ ___ ___
o Types and properties of oil dielectrics – paraffinic, hydrocarbon, napthenic, aromatic and synthetic. Dielectric additives	___ ___ ___ ___ ___ ___
Category VI. - Types of Processes Including: Die-Sinking, Wire and Micro EDM	
o Sinker design including: C-frame, compound table, gantry	___ ___ ___ ___ ___ ___
o Sinker generator including: RC/DC/AC, avg. current, peak current, capacitors, carbide circuitry, fine finish circuitry, effects of dielectric additives, etc.	___ ___ ___ ___ ___ ___
o Wire design including: C-frame, compound table, gantry	___ ___ ___ ___ ___ ___
o Wire generator including: DC/AC, anti-electrolysis circuitry, carbide circuitry, fine finish circuitry, adaptive control, effects of dielectrics and additives	___ ___ ___ ___ ___ ___

o Machining size/shape constraints	___ ___ ___ ___ ___ ___
o Differentiate the types and limitation of each	___ ___ ___ ___ ___ ___
o Explain advantages, disadvantages and industrial applications of: EDM, WEDM, ECM, ECG, ECDeburring, ECPolishing, small holes drilling with EDM, micro EDM, precision/micro WEDM	___ ___ ___ ___ ___ ___
o Explain present development trends (industry and academia) in: EDM, WEDM, ECM, ECG, ECDeburring, ECPolishing, small holes drilling with EDM, micro EDM, precision/micro WEDM; laser machining, water jet cutting, abrasive jet cutting	___ ___ ___ ___ ___ ___
o Explain advantages, disadvantages and industrial applications of: laser machining, water jet cutting, and abrasive jet cutting	___ ___ ___ ___ ___ ___

Appendix G
Follow-up Letter – Round Two

Expert Panel Member,

I hope you have found time in the past week to review round ones' results and provide input for round two. With a small panel of experts your participation is appreciated and very important to the furthering of this study. Please complete round two as soon as possible and return it for the development of this studies conclusion. If you might have any questions please contact me.

Thank you,

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Appendix H

Delphi Instrument – Round Two Compilations

Category I. - The History and Evolution	Extremely Unnecessary	Very Unnecessary	Unnecessary	Necessary	Very Necessary	Extremely Necessary
o Knowledge of early research and development including: World War II, The Lazerankos, Americans/Ex-cello, Elox, Swiss/AGIE, Charmilles, Japanese/IJR Research, Japax, Sodick, Makino			**OI**	X		
o Explain historic evolution of non-traditional material removal processes including a rough timeframe for each			O	**IX**		
o Explain industrial applications of non-traditional material removal processes				I	**O**	X
o Explain basic requirements, development and influence of computer control in non-traditional material removal processes				**XO**	I	
o Explain adaptive control and present use of it in non-traditional material removal processes			X	**O**	I	
o Explain present development trends in adaptive control for non-traditional material removal processes			I	**XO**		

Category II. - Theories of Material Removal	
o Name principal types of material removal mechanisms including: Electro-chemical (ECM), Thermo-mechanical, Thermo-electric, Electro-mechanical	___ ___ ___ _**OI**_ _X_ ___
o Estimate the material removal rate	___ ___ ___ ___ _**XOI**_ ___
o Understand the mechanism. Effect of polarity on parameters and apply to wire, die sinking, and micro EDM	___ ___ ___ ___ _**XO**_ _I_
o Explain physical principles underlying each type of material removal mechanism	___ ___ ___ ___ _**OI**_ _X_
o Explain drawbacks of each theory	___ ___ ___ _X_ _**OI**_ ___
o Name applications of each theory as utilized in commercial software	___ ___ _**XOI**_ ___ ___ ___
o Explain principal theories used to describe and quantify each type of material removal mechanisms	___ _I_ ___ _**O**_ _X_ ___
Category III. - The Process Mechanism	
o EDM theory including: voltage, amperage, ionization, vapor pressure, dielectrics, electrode materials, workpiece materials, etc.	___ ___ ___ ___ _**OI**_ _X_
o Wire selection including: brass, simple coated, diffusion annealed, moly, tungsten	___ ___ ___ ___ _**OI**_ _X_
o Electrode selection including: metallic/graphite	___ ___ ___ ___ _I_ _**XO**_
o Know the dominant parameters	___ ___ ___ ___ _**OI**_ _X_
o Explain process mechanism for: EDM, WEDM, ECM, ECG, ECDeburring, small holes drilling with EDM, micro EDM, precision WEDM	___ ___ _I_ ___ _**O**_ _X_

o Explain limitations for each process from perspective of materials: workpiece, tool, environment (fluids)	___ ___ ___ _O_ _**I**_ _X_
o Explain technological, economic and environmental limitations to each process	___ ___ ___ _**OI**_ ___ _X_
o Explain industrial applications of each process	___ ___ ___ _O_ _**I**_ _X_
o Explain degree of precision in generation of: shape, surface quality, subsurface damage, chemical composition change for each process	___ ___ ___ _**OI**_ ___ _X_
Category IV. – Pulses	
o Knowledge and be able to use RC/DC/AC generators	___ ___ _**XO**_ ___ _I_ ___
o Knowledge of electrical arcs and preventions of shorts	___ ___ ___ _**XOI**_ ___ ___
o Knowledge and application of typical ranges for common material (e.g. steel)	___ ___ _I_ _**O**_ ___ _X_
o Choose appropriate polarity, pulse type and generator type given: technological parameters of the process, machine tool used, tools, materials machined, electrode material, geometric features of machined shape, duty cycle on material removal rate	___ ___ _I_ _**O**_ _X_ ___
o Explain general influence of: on time, off time, shape of pulse and open gap/working voltage/current control in the gap, on outcomes of EDM process (spark gap size, surface generated, electrode wear/build-up/breakage, possibility of generating sharp features, possibility of generating small features)	___ ___ ___ ___ _**OI**_ _X_
o Choose appropriate pulse settings for given technological task: material machined, part size, surface roughness desired, geometric features of machined shape electrode used, tolerance of subsurface stresses and metallurgical change	___ _I_ ___ ___ _**XO**_ ___

Category V. - Dielectric Fluids for EDM	
o Name basic types of fluids used in all types machining in EDM, WEDM, ECM, ECG, ECDeburring, small holes drilling with EDM, micro EDM, precision WEDM	___ _I_ ___ _**O**_ ___ _X_
o Explain fluids' advantages, disadvantages, and cost of initial purchase and maintenance	___ ___ _I_ _**O**_ _X_ ___
o Understand mechanism of ionization	___ ___ ___ _X_ _**OI**_ ___
o Dielectric type and effects upon workpiece surface finish, surface integrity	___ ___ ___ _X_ _**O**_ _I_
o Properties of water dielectrics	___ ___ ___ _**OI**_ _X_ ___
o Dielectric type and effects upon workpiece chemistry and metallurgy	___ ___ ___ ___ _**XO**_ _I_
o Types and properties of oil dielectrics – paraffinic, hydrocarbon, napthenic, aromatic and synthetic. Dielectric additives	___ ___ ___ _I_ _**X**_ _O_
Category VI. - Types of Processes Including: Die-Sinking, Wire and Micro EDM	
o Sinker design including: C-frame, compound table, gantry	___ _O_ _**I**_ _X_ ___ ___
o Sinker generator including: RC/DC/AC, avg. current, peak current, capacitors, carbide circuitry, fine finish circuitry, effects of dielectric additives, etc.	___ _O_ ___ _**XI**_ ___ ___
o Wire design including: C-frame, compound table, gantry	___ _O_ _**I**_ _X_ ___ ___
o Wire generator including: DC/AC, anti-electrolysis circuitry, carbide circuitry, fine finish circuitry, adaptive control, effects of dielectrics and additives	___ _O_ _**X**_ ___ _I_ ___
o Machining size/shape constraints	___ _O_ ___ ___ ___ _**XI**_

○ Differentiate the types and limitation of each	___ _O_ ___ ___ _**X**_ _I_
○ Explain advantages, disadvantages and industrial applications of: EDM, WEDM, ECM, ECG, ECDeburring, ECPolishing, small holes drilling with EDM, micro EDM, precision/micro WEDM	___ ___ ___ _**OI**_ ___ _X_
○ Explain present development trends (industry and academia) in: EDM, WEDM, ECM, ECG, ECDeburring, ECPolishing, small holes drilling with EDM, micro EDM, precision/micro WEDM; laser machining, water jet cutting, abrasive jet cutting	___ ___ ___ _**OI**_ _X_ ___
○ Explain advantages, disadvantages and industrial applications of: laser machining, water jet cutting, and abrasive jet cutting	___ _O_ ___ _**I**_ ___ _X_