Session 2563

Integration of Real Forming Experience in a Virtual Forming Course

Raghu Echempati

Department of Mechanical Engineering
Kettering University
Flint, MI 48504

Abstract

The main objective of this paper is to present the current status of the course ***ME-510: Introduction to the Computer Simulation of Metal Forming Processes*** that was developed at Kettering University (KU). Currently, this course is offered independent of another course "Sheet Metal Forming", which deals with the real forming technology. However, 3 to 5 students take both these classes. The ME-510 class is well received by both the students and the participating industrial sponsors. At the ASEE2000 Conference in St. Louis, MO, the background, philosophy, benefits and limitations of offering a course sequence on the real and virtual forming was discussed. Due to a recent curriculum reform at Kettering University, many courses were revised, and wherever possible some of the courses or course topics have been integrated. With regard to the above mentioned two courses on metal forming, it became evident that there may be a possibility of integrating them in to a basic single course that covers both real and virtual forming scenarios. Initial feedback of the students taking these two classes supports this idea. This new proposal is still in its discussion stage and the resulting outcomes of such integration if any, will be presented in a future conference. This paper outlines the integration of some of the real forming technology in to the virtual forming course. In addition, the evaluation and assessment tools developed for this course will be addressed. Also, the results of some of the undergraduate/graduate student applied research projects will be presented in more detail at the meeting, and the role of tool-based learning discussed. Due to the large size of the simulated computer graphics files, the detailed results will only be presented at the conference meeting. Finally, the author's perception of the course layout of a possible integrated course is presented in an Appendix.

Introduction

At the ASEE 2000 Conference in St. Louis, MO, the philosophy behind the development of a course sequence in the area of real and virtual *metal forming processes* at Kettering University

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(KU) (formerly, GMI Engineering & Management Institute) in Flint, Michigan has been discussed. In this paper, the current status of the ***ME-510: Introduction to the Computer Simulation of Metal Forming Processes*** course is briefly discussed, followed by the course learning objectives and outcomes. Also, the assessment and the evaluation tools developed for this course are presented. Finally, the applied research done on different aluminum alloys is outlined and discussed.

As mentioned in the metal forming literature [1-5], the use of "soft tooling" has already gained popularity in the stamping industries compared to "hard tryouts", not only because of the cost and better understanding of the science behind real forming, but also due to the availability of powerful computational tools. The Virtual Metal Forming course has 4 credits with 4 to 6 contact hours and is currently offered at the mezzanine (500) level, which means that both graduates and undergraduates can take this course. The undergraduates taking this course may also receive graduate credits if they choose to do Masters at KU. The enrollment in this course steadily increased (from 3 to 11) in the past 4 to 5 terms, including the term in which this course was offered as a "Pilot Course". The computational facilities although still limited for this course, have also been upgraded and students now use the faster computers with larger disk quota per student. The number of computer laboratory experiments was increased from three or four to six different experiments – 3 experiments based on one-step solver (PAM-QuickStamp©) and the other three based on incremental solver (DYNAFORM©). The overall quality of home works and projects has also tremendously improved. The student satisfaction level for this course has steadily increased. The goals and objectives of this course follow the mission and goals of KU in general, and the goals of the mechanical engineering department in particular. The overall university goal is to enhance the undergraduate and graduate education through hands-on education and to promote inter-disciplinary applied research activities.

To accomplish some of these goals, the developmental efforts focussed on further enhancement of the virtual forming course. The catalog description of this course is outlined in Appendix I. In lieu of the new curriculum development at KU that will be in place beginning July 2001, the students will have limited choice on the number of electives th"ey can choose within a particular Mechanical Engineering "Concentrations". Thus the possibilities of integrating the two current elective courses on real and virtual metal forming in to a single stronger course are being explored, the results of which will be presented in a future conference. In the meanwhile, the modified course layout of ***ME-510: Introduction to the Computer Simulation of Metal Forming Processes*** is presented in Appendix I. The modifications are in terms of integration of a limited real forming experience in to the virtual forming course.

Itemized objectives of the detailed plan for this course:

I. Enhancement of the existing Computer Simulation of Metal Forming course
   (i) upgrade the existing CAE laboratories by procuring a high speed computer server such as the Sun Enterprise 3500 with enough memory capacity and 70^{+} GB of disk space to educate more students and for the thesis students to

run simulation of some of the actual sheet metal parts from their co-op companies

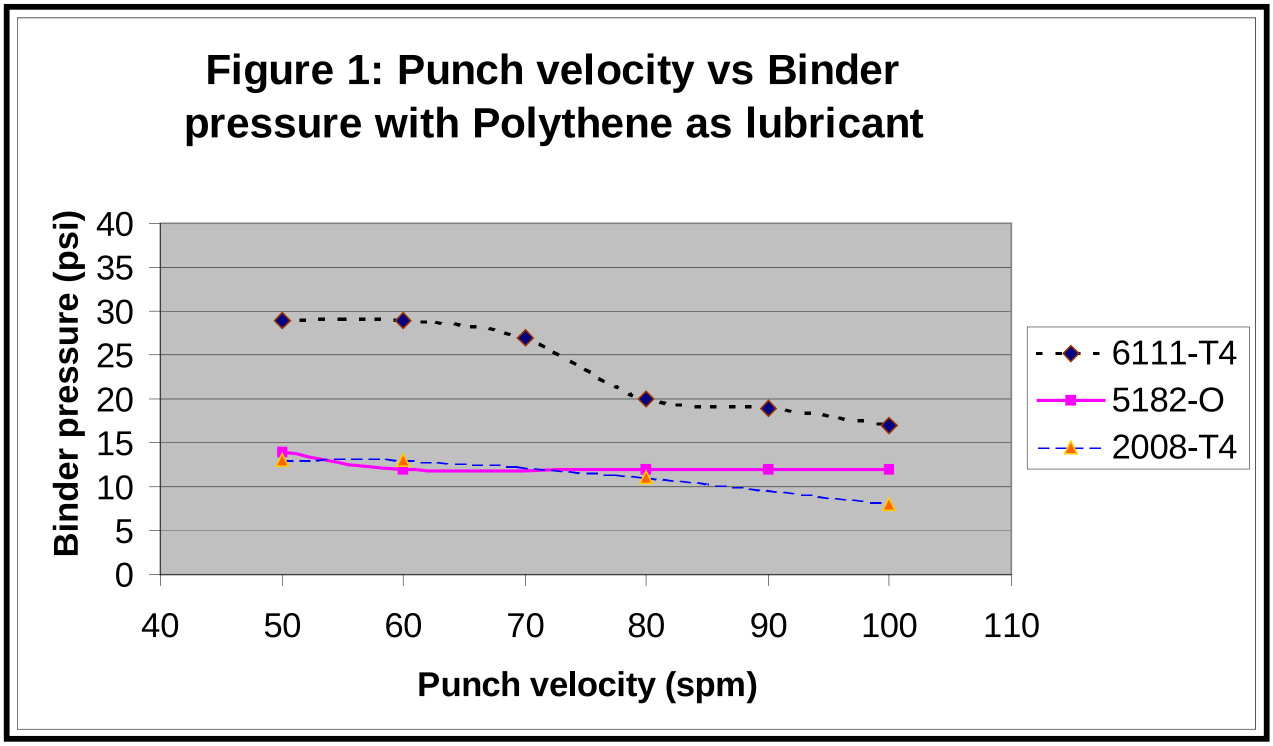
(ii) refine the developed handouts, class notes and computer laboratory manual

(iii) enhance the faculty research in virtual forming and support the integration of applied research into the undergraduate curriculum

(iv) introduce an advanced virtual forming course at the graduate level

As mentioned before, there are some changes in place both in terms of course content and structure for the ME-510 class. The students' start off by observing the one-step (QuickStamp©) and the incremental (DYNAFORM/LS-DYNA©) results of the example benchmark problems provided by these software companies. They then model and perform simulation of simple stamped parts following the tutorials provided to them. For their project, students attempt to perform parametric studies to model and simulate the bending and drawing operations. In order for the students to get exposed to the real-world scenario, 1 to 2-hour real forming laboratory experiments are demonstrated. The total contact hours for this course are four to six. Many of the lectures will be spent on covering the concepts and the two 2-hour laboratories are used to engage the students in the training of the software and in performing the virtual forming experiments. The significant change in this course is to teach the students the importance of validation of the virtual try-outs with the real forming technology where possible until such time they gain experience in the computational mechanics, in order to correctly predict formability of sheet metals. This mastery of knowledge usually requires a graduate level exposure in the advanced metal forming area.

In terms of the undergraduate and graduate student research, formability studies on 6111-T4, 5182-O and 2008-T4 example aluminum materials have been undertaken. This applied research also uses integration of real and virtual forming technologies. As a matter of scientific interest, it was found through the experimental studies that friction and binder pressure plays a very important role in the consistent and successful forming of an example cylindrical cup. Some of these observations are validated through computer simulation using the QuickStamp© and the Dynaform© software. Further studies are in progress to measure the spring back of the aluminum cups and to predict the same by virtual forming. The complete graphical results being very large will only be presented at the meeting. Figure 1 shows an example plot of the binder pressure as a function of punch velocity when the friction is varied. The friction is changed by inserting a paper towel or by using a polythene sheet between the die and the blank. As can be seen, for 6111-T4 and 5182-O blank materials, the binder pressure needed to be reduced as the punch velocity increases. The reason for this is due to the very low to negative m-value (strain rate sensitivity factor) for sheet aluminum material. The change in binder pressure for 2008-T4 is not significant compared to the other two materials.



Evaluation and dissemination tools

In addition to the on campus tests, homework, laboratory reports, new evaluation and assessment questionnaire forms have been prepared as a part of student survey on this course. A sample form of the detailed survey is enclosed in Appendix II. For dissemination of results, once again, several methods are proposed. These include: presentation of technical papers in conferences (for example, ASME and ASEE), technical seminar and/or workshop presentations, continuing education to part-time students and practicing engineers, seminar demonstration/poster-sessions for high school students organized through ASME/SME professional societies during the Engineers Week and during the "Discover Kettering Universit"y" Day, conducting a stamping symposium on campus, and finally, development of web page and internet access to lecture materials and simulations.

Conclusions

This paper outlines the current status of a virtual metal forming course at KU. Also, the philosophy of a possible future integrated course and an advanced graduate level course in Metal Forming is briefly mentioned. This will be presented in a future paper.

Bibliography

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Biography

Raghu Echempati is currently an assistant professor at Kettering University (formerly, GMI Engineering & Management Institute). He received his undergraduate degree from Andhra University, Waltair (India) and his Master of Technology and Ph. D. from the Indian Institute of Technology, Kharagpur (India), all in the field of Mechanical Engineering. He was a post doctoral research associate (NSF funded) with late Professor George N. Sandor at the University of Florida, Gainesville, Florida in 1979. He later worked at several Universities, including the Indian Institute of Technology, The Ohio State University, Washington State University, Michigan Technological University and The University of Mississippi. Raghu Echempati is a registered professional engineer in the State of Mississippi, and a certified manufacturing engineer issued by the Society of Manufacturing Engineers. He has several research publications in the areas of Dynamics, Mechanisms, Vibrations and Manufacturing. He is an ASME Fellow and a member of ASEE, SAE, and SME.

Appendix I

Course Description

ME-510: Introduction to Computer Simulation of Metal Forming Processes (2-4-4)

Catalog Data: **ME-510: Introduction to Computer Simulation of Metal Forming Processes (2-4-4)** 4 Credits (2 Lectures, 2 two-hour laboratories; 6 total contact hours). The main aim of this course is to introduce the concepts of metal forming processes, including the sheet metal forming, and to expose some of the latest computational techniques for modeling and simulation of the same. Modern high-speed computer aided design technology is introduced here to study the behavior of the material during metal forming process, including the study of the strain pattern during the metal forming process. The class room theory and concepts covered are complimented by hands-on laboratory demonstration. Validation of some of these real stamping laboratory experiments is done using the standard one-step and incremental software such as QuickStamp®, FastForm® and LS-DYNA®. These computer solution procedures will be compared and discussed with emphasis on the sheet metal forming design techniques.

Prerequisites by Topics:

1. Ability to understand and solve problems dealing with basic manufacturing processes and engineering materials.
2. Ability to model and to solve problems dealing with mechanics and design of rigid bodies.
3. Ability to use a CAD software for computer visualization, solid modeling and design communication.

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Textbook: None, Class Notes will be provided

Reference: William F. Hosford and Robert M. Caddell, **Metal Forming – Mechanics and Metallurgy**, Prentice-Hall, Inc. 2nd Edition, 1995.
Tylan Altan, Soo-Ik Oh and Harold L.Gegel, **Metal Forming – Fundamentals and Applications**, American Society for Metals, 1992.
QuickStamp®, **FastForm**® and **LS-DYNA**® Lab manuals.
N.M. Wang and S. C. Tang (editors), **Computer Modeling of Sheet Metal Forming Process**, The Metallurgical Society, Inc., 1985.
S. R. Reid, **Metal Forming and Impact Mechanics**, 1995.

Coordinators: Raghu Echempati

Educational Outcomes:

The educational outcome of this course is to teach students to integrate the principles of manufacturing processes, concepts of engineering materials, stress-strain behavior, plasticity, solid modeling and finite element analysis and simulation for large deformation of sheet metal parts. The forming theory is complimented by hands-on laboratory demonstrations that include measurement of strain using the circle grid analysis and the forming limit diagrams (FLDs). The computer simulation includes understanding of deformation pattern and strain behavior of 3D sheet metal parts and an ability to understand and interpret the results. This course will use automotive and other real-world industrial applications to extend the fundamentals introduced in Manufacturing Processes, Engineering Materials, Solid Mechanics, and CAE to perform virtual formability studies of sheet metal parts. Other topics such as rolling, forging and extrusion will also be covered. Deformation behavior of axisymmetric, symmetric and nonsymmetrical sheet metal parts will be discussed. For the computer simulation software tools such as I-DEAS©, DYNAFORM© and QuickStamp© will be used to perform the modeling and analysis. Several practical design projects will be demonstrated during the term of this course.

Educational Objectives:

Objective 1:	To enable the student to apply the fundamental concepts learned in manufacturing processes, mechanics of materials and engineering materials to the large deformation processes.
Objective 2:	To enable the students to learn the fundamentals of computer simulation of metal forming processes.
Objective 3:	To enable the student's understanding of the benefits of real and virtual forming technology and its consequences on the early stages of a sheet metal product design.
Objective 4:	To enable the student's understanding of the latest techniques for measurement of strain through circle grid analysis in the laboratory and by finite element modeling on the computer.
Objective 5:	To enable the student's understanding of the behavior of metal flow during the metal forming process.
Objective 6:	To enable the student's critical understanding of the defects in stamped parts and the obstacles to accurately model these defects in the computer simulation in an effort to do parametric studies.
Objective 6:	To enhance the student's understanding and correct interpretation of the results of a simulation and to develop strategies to improve the product and process design based on the results obtained.

Lecture Topics:

Week #	Topic	Time
1.	Introduction; Materials; Tensile Test Parameters; Methods of calculating n-value	(2 Hrs)
2.	Introduction to bulk and sheet metal formability; Strain and Circle Grid Analysis	(2 Hrs)
3.	Understanding the major, minor and thickness strains; FLDs	(2 Hrs)
4.	Simple Bending Operations; Software demonstration and training	(2 Hrs)
5.	One-step and Incremental Solvers; Modeling considerations	(2 Hrs)
6.	Test 1	
7.	Bending Simulation using I-DEAS®/ Dynaform®/ LS-DYNA®; Theory	(2 Hrs)
8.	Simple Drawing Operations – Hemispherical cup draw; Theory	(2 Hrs)
9.	Deep Drawing Operations; Laboratory Demonstrations of Bending and Drawing	(2 Hrs)
10.	Take-home Test 2	
11.	Comparison of results between the two software	(2 Hrs)
12.	Interpretation and Discussion of results; Course Review	(2 Hrs)

Sheet Metal Laboratory Usage:

In addition to the lectures, a hands-on laboratory demonstrations are planned for the semester. These will be held in the Sheet Metal Laboratory.

Computer Usage:

Unix or Windows NT® based software installed on metruck and/or megalaxy servers, and/or Windows NT® server will be used.

Design Project:

Each student is either assigned a project by the professor, or is allowed to select a project of interest to their sponsors. The project should involve performing the simulation of a sheet metal part by varying the different design and process variables. The outcome of the project report should provide valuable information about the product and process design in the early stages of a manufacturing product design. Also, the study should provide guidelines about the process capability based on interpreting the output deformation and strain histories of the final product.

Proposed Software and Laboratory: Unix-based DYNAFORM® (Finite Element Model Builders of LS-DYNA®) and QuickStamp® that are installed on the metruck/galaxy servers will be used.

Estimated ABET Category Content:

Mechanical Engineering:4 credits **Design Credits: 2 credits**

The author's perception of the course layout for a future integrated metal forming course is given in the table below.

Week	2-Hour Lecture Topic	1st 2-Hour Laboratory Experience	2nd 2-Hour Laboratory Experience
1	Introduction; Materials; Tensile Test Parameters; Methods of calculating the metal forming parameters	Calculation of n and K-values from tensile test data; plastic anisotropy r-value	Manufacturing Simulation; Demonstration and Discussion of Simulation Examples
2	Plastic Strain, Strain Rate, Circle Grid Analysis and FLD	Gridding and Forming; Creating the FLD	Modeling Considerations in Finite Element Analysis
3	Blanking Operations; Blank Size	Software Tools – their capabilities and limitations	Linear versus Nonlinear FEM; Preprocessing
4	Simple Bending Operations	Bending Laboratory; Strain Measurements	Bending Simulation using I-DEAS and QuickStamp
5	Test 1	Drawing Laboratory I	Bending Simulation using I-DEAS/ Dynaform/ LS-DYNA Lab
6	Bending Simulation using I-DEAS/ Dynaform/ LS-DYNA Theory and Demonstration	Drawing Laboratory II	Hemispherical Cup Draw Simulation
7	Drawing Operations I	Drawing Laboratory III	Cylindrical Cup Draw Simulation I
8	Drawing Operations II	Hole Expansion Laboratory	Cylindrical Cup Draw Simulation II
9	Other Sheet Metal Operations; Effect of Friction	Rectangular Blank Laboratory	Symmetrical Square Pan Draw Simulation I
10	Take-home Test 2	Final Project	Symmetrical Square Pan Draw Simulation II
11	Course Review	Final Project	Final Project

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Appendix II

Sample Student Evaluation Survey for Virtual Metal Forming Course

Now that the term is almost over, we would like to know your assessment of the impact hands Virtual Sheet Metal Forming has had on your ability to learn sheet metal forming and think critically. Your responses to this questionnaire are confidential; no one will see your individual responses except the Office of Institutional Research. Dr. Raghu will receive a summary of the results but not the questionnaire's themselves. Your frank responses are an important part of building a composite picture; we appreciate your participation.

Current information about yourself:

Major (specialty) _________________________________ Co-op Employer ______________________________

Planned Career: Please check one of the following categories.

Employment in Mechanical Engineering after BS ______________________________
Graduate Education in Mechanical or Manufacturing Engineering ______________________________
Graduate School in other field ______ What field? ______________________________
Other ______ If other, please explain: ____

____

A. Assessment of ME-510: Virtual Sheet Metal Forming Course

1. **Student Assessment of the intrinsic value of experiences in ME-510 lecture and hands-on computer laboratory**.

a) I am more successful at grasping the sheet metal forming concepts taught in the lecture course as a result of hands-on experience with the computer laboratory.
Strongly Agree Agree Disagree Strongly Disagree

a) I already have some exposure to the hands-on digital metal forming at my co-op.
Strongly Agree Agree Disagree Strongly Disagree N/A

b) 1 am more interested in digital manufacturing as a result of hands-on experience with virtual CAE tools used in the laboratory exercises than the lecture classes.
Strongly Agree Agree Disagree Strongly Disagree

c) The use of computer laboratory experience in ME-510 has made me more interested in enrolling in undergraduate research than I would have been otherwise.
Strongly Agree Agree Disagree Strongly Disagree

d) The incorporation of hands-on computer laboratory in the ME-510 course enhanced my ability to learn "what-if" scenarios in understanding concepts presented in lectures and laboratory.
Strongly Agree Agree Disagree Strongly Disagree

e) The required computer generated lab reports helped me organize my work and in presenting the results (using MS-Word, MS-Excel and other graphical images) that made more sense.
Strongly Agree Agree Disagree Strongly Disagree

f) The use of Dynaform (or similar) software to create various virtual tools (die, punch, blank and binder) made me understand the power of "digital" technology as explained in the lecture.
Strongly Agree Agree Di"sagree Strongly Disagree

g) The use of automatic (finite element) meshing ability provided in the software is moderately easy and clear.
Strongly Agree Agree Disagree Strongly Disagree

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h) The computer lab experience exposed me to better understand the underlying assumptions of virtual (or digital) forming.
Strongly Agree Agree Disagree Strongly Disagree

i) The use of (Dynaform) software is relatively easy.
Strongly Agree Agree Disagree Strongly Disagree

j) The use of simple bending simulation to analyze the outcomes of sheet bending made the formability and major strain results easier to understand than they would have been otherwise.
Strongly Agree Agree Disagree Strongly Disagree

k) The outcome of major strain results on bending parts is more meaningful to me because I analyzed the results myself using the incremental solver.
Strongly Agree Agree Disagree Strongly Disagree

l) With CAE software, it is easy to understand the principles behind meshing a part using different types of elements.
Strongly Agree Agree Disagree Strongly Disagree

m) The use of different mesh patterns for bending strain predictions is very tiresome.
Strongly Agree Agree Disagree Strongly Disagree

n) I understand the difference between incremental solvers and one-step solvers more through computer lab assignments than in the lecture.
Strongly Agree Agree Disagree Strongly Disagree

o) The use of cup drawing simulation made me understand the effects of varying tool geometric parameters (die entry, punch nose radii and clearance) and material parameters on the formability of cups.
Strongly Agree Agree Disagree Strongly Disagree

p) The outcome of major and minor strain predictions using CAE tools on the simulation of various axisymmetrical cups is more meaningful to me because I analyzed the results myself by using the postprocessor tools (thinning and FLD) that are available in the software.
Strongly Agree Agree Disagree Strongly Disagree

q) The use of auto meshing menu for meshing the die, punch, blank and binder of drawn cups is very tiresome.
Strongly Agree Agree Disagree Strongly Disagree

r) Overall, the meshing exercises made me understand the metal forming concepts presented in the lectures.
Strongly Agree Agree Disagree Strongly Disagree

s) Overall, the meshing of tools in all the lab exercises is very tiresome.
Strongly Agree Agree Disagree Strongly Disagree

t) Overall, the computer laboratory experience developed my problem-solving abilities in metal forming.
Strongly Agree Agree Disagree Strongly Disagree

u) Overall, through the laboratory experience given to me in this class, I can predict the "what-if" scenarios for all other types of geometry of tools, including for non-axisymmetric parts.
Strongly Agree Agree Disagree Strongly Disagree

v) Overall, ***it is now very easy*** to conduct simulation studies of more complicated stamping parts.
Strongly Agree Agree Disagree Strongly Disagree

w) Overall, there seems to be a lot of ***waiting time either because of*** large number of groups or because of frequent problems and difficulties with software or the computers.
Strongly Agree Agree Disagree Strongly Disagree

x) Overall, I was able to gain insights into metal forming, from the use of virtual experiments that would not have been possible otherwise.
Strongly Agree Agree Disagree Strongly Disagree

y) Overall, I think that more time was spent per simulation than each simulation really deserves.
Strongly Agree Agree Disagree Strongly Disagree

z) Overall, I think that the computer disk space allocated to me is not enough.
Strongly Agree Agree Disagree Strongly Disagree

aa) Overall, I think that I could have accomplished more computer simulations if more computer disk space or faster computer facilities are available to me.
Strongly Agree Agree " Disagree Strongly Disagree

bb) I would recommend this and an advanced course if any, to others even though the course required more work than some other courses.
Strongly Agree Agree Disagree Strongly Disagree

cc) I think ***this course is more beneficial for me than the real metal forming*** course (if taken).
Strongly Agree Agree Disagree Strongly Disagree

dd) I think ***this and the real forming course should be offered sequentially*** as are currently offered.
Strongly Agree Agree Disagree Strongly Disagree

ee) I think that it is ***beneficial to combine both these courses in to a single introductory course***, followed by an advanced elective course.
Strongly Agree Agree Disagree Strongly Disagree

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1. **Assessment of the type of learning required excelling in the ME-510 course**.

a) For most part, since the entire course is composed of structured lectures and structured computer laboratory exercises, I relied mostly on passive learning techniques (learning by following directions of others or reading material provided by others) than on active learning (learning by discovering knowledge and thinking for myself.
Strongly Agree Agree Disagree Strongly Disagree

b) I was able to obtain the desired results in the structured simulation exercises using passive learning skills (learning by following directions of others or reading material provided by others).
Strongly Agree Agree Disagree Strongly Disagree

c) In the test, I engaged in active learning more than passive learning in order to understand the strain behavior of the stamped part given to me for simulation.
Strongly Agree Agree Disagree Strongly Disagree

d) Personally, simulating a cup drawing using my own coefficient of friction for lubricants made me engage in active learning.
Strongly Agree Agree Disagree Strongly Disagree

e) High levels of critical thinking were required to interpret the simulation results (and FLD) for the cup drawn using my unknown lubricant.
Strongly Agree Agree Disagree Strongly Disagree

f) In general, the use of virtual metal forming techniques to understand the formability and to form different parts with different geometry and shapes require critical thinking.
Strongly Agree Agree Disagree Strongly Disagree

2. **Assessment of students' opinion of the importance of virtual metal forming course.**

a) If I were to become a professional metal forming engineer, the ability to understand the theory presented in lectures and the computer numerical skills learned in the simulation laboratory exercises would be essential.
Strongly Agree Agree Disagree Strongly Disagree