

2006-49: REVAMPING MECHANICAL ENGINEERING MEASUREMENTS LAB CLASS

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Revamping Mechanical Engineering Measurements Lab Class

Abstract

Measurements Lab is a core junior course for mechanical engineering majors in the Department of Mechanical Engineering at Lamar University. The main objective of the course is to train students to be able to use various instruments and equipments needed in a mechanical engineer's career. This paper discusses the revamping of the course describing each experiment and the related materials, the relevance of each new experiment to ABET outcomes related to experimentation, and the evaluation of student projects and their assessments. Responses and feedback from students are presented to evaluate the effectiveness of new experiments and group projects.

Introduction

Laboratories are essential for education and training of engineers as they provide hands-on experiences and demonstrate applications of theoretical principles to the real-world engineering problems. There are two required laboratory classes in the curricula of mechanical engineering at Lamar University: MEEN 3311 Measurements Lab and MEEN 4313 Materials Lab. These lab courses were the principal courses designed to meet the ABET EC 2000 outcome (b) related to experimentation: an ability to design and conduct experiments as well as to analyze and interpret data. This paper will discuss the Measurements Lab, a core junior level course for mechanical engineering majors in the Department of Mechanical Engineering at Lamar University. The course is a two-credit hour class with one 1-hour lecture and one 3-hour lab session per week. The main goals of the course are

- (a) to develop and promote students' ability to identify, select, and use various instruments and equipment
- (b) to develop and promote students' ability to conduct experiments, to analyze experimental data, and to interpret the experimental results.

The course covers technical writing and presentation, design of experiments and error analysis, and data acquisition concepts using DataStudio^{®1} and LabVIEW^{®2} software packages. Laboratory session covers several experiments including measurement of fundamental properties such as pressure, temperature, flow, humidity, and mechanical strain. Moreover, experimental analyses of engineering systems such as vapor compression refrigeration cycle and heat exchanger testing are also included in the lab sessions. The present experiments in the lab are several years old so the department has recently decided to revamp and introduce new experiments to replace some old ones. As discussed previously, this course is one of the two courses to evaluate the ABET outcome related to experimentation. As a result, the revamping of the course is an ideal opportunity to incorporate new materials with which the students will be able to demonstrate higher learning skills such as application, analysis, synthesis, and evaluation. To deal with new experiments and materials to be introduced to the course, the lab manual is also

revised to reflect the new experiments. The major course component to develop higher learning skills for students is by introducing group projects related to engineering experimentation. This paper discusses the revamping of the course describing experiments, projects, and related materials, relevance of these experiments and projects to ABET outcomes related to experimentation, and the evaluation of student projects and their assessments. Responses and feedback from students are also presented to evaluate the effectiveness of new experiments and group projects.

Course Description

The following is the course description listed in the undergraduate catalog:

MEEN 3210: Measurements Laboratory Credit 2 (1 hour lecture, 3 hour lab)

Theoretical knowledge and practical uses of engineering measurement instruments and equipments are introduced. The course covers technical writing and presentation, design of experiments and error analysis, and data acquisition concepts using DataStudio and LabVIEW software packages. Laboratory session covers measurement of fundamental properties: pressure, temperature, flow, humidity, and strain. Experimental analysis of engineering systems: vapor compression refrigeration cycle, geothermal heat pump, internal combustion engine, and wind tunnel testing, are also included in the lab sessions.

The objectives of the course are

- (a) To understand the theory and application of measuring instruments and equipment
- (b) To discuss statistical methods used to design experiments and evaluate experimental errors
- (c) To provide hands-on experience using laboratory instruments to measure pressure, temperature, flow, humidity, and strain
- (d) To provide hands-on experience in experimental analysis of engineering systems such as refrigeration cycle, centrifugal pumps, and heat exchangers

The old textbook is Experimental Methods for Engineers 7th edition by Holman³. After revamping the course the instructor has decided to use a new textbook, Introduction to Engineering Experimentation, 2nd Edition by Wheeler and Ganji⁴. Holman's book is still used as a reference. Additional references are also added, Pocket Book of Technical Writing for Engineers and Scientists by Finkelstein⁵ and LabVIEW 6i Student Edition by Bishop⁶, to help with technical writing (the former) and LabVIEW (the latter) respectively. The lab manual is also revised to reflect the modifications to old lab experiments and the introduction of new experiments.

The prerequisites for the class are completion of junior level thermodynamics and fluid mechanics courses. The evaluation of the class consists of lab reports (30%), lab memos (30%) and design project (40%). The laboratory reports are divided into two categories: full lab report and lab memo. The full lab report requires the inclusion of the following sections:

- Grade Sheet
- Cover Sheet
- Abstract
- Table of Content
- Nomenclature
- Introduction
- Objectives
- Apparatus
- Theory: (if needed)
- Results
- Discussions
- Conclusions
- Citations
- Appendix

The students are required to submit three full reports in the semester with each one worth 10% of the final grade. The lab memo is a much shorter version of the full lab report and the following sections are required in the lab memo:

- Grade Sheet
- Introduction
- Objectives
- Results
- Discussions
- Conclusions

The students are required to submit five lab memos with each one worth 6% of the final grade. The ability to effectively communicate the technical materials is very important for engineers. Thus, 30% of the total grade of each lab report and lab memo is assigned to the writing style, report format, word usage, and grammar.

Laboratory Experiments

In this course, the experiments can be categorized into two types: experiments dealing with measurements of fundamental properties such as pressure and temperature, and experiments dealing with analysis of engineering systems such as centrifugal pumps, heat exchangers, and vapor compression refrigeration systems. Typically the enrollment in the course is about 20 students so the students are divided into groups of 3 to 4 students. Each lab is conducted by every group but each student is required to prepare and submit his or her own report for the lab.

The lab experiments dealing with fundamental properties are discussed first. There are five experiments in this category: one each for measuring pressure, temperature, humidity, flow, and strain. The lab for pressure is divided into three parts: calibration of three pressure measurement devices, a Bourdon type pressure gage, a pressure transducer, a digital pressure gage, using a dead-weight tester; measurement of pipe pressure drop for four different pipe sizes and

materials; and measurement of pressure drop across a gate valve for three valve opening settings. The only modification to this experiment is to replace Bourdon gages for pipe pressure drop lab with digital pressure gages for better readability and accuracy.

The lab for temperature is divided into four parts, and all four parts are new experiments: calibration of thermocouples, determination of time constants of two different thermocouples, calibration of an infrared thermometer, and temperature mapping of a natural gas flame using a K-type thermocouple. All the students should understand the importance and need for calibration of an instrument. Thus, two calibration experiments for temperature measurement are implemented. The first experiment utilizes a constant temperature liquid bath to calibrate type J and type T thermocouples. With rapid advances in infrared thermography, the use of infrared thermometer has become more common in industry settings, for example, identifying hot spots in an industrial furnace. Thus, an experiment is implemented where an infrared thermometer is calibrated using a three-point calibrator. In measuring temperature in a dynamic environment, the time constant of the sensor plays a critical role for accurate results. Thus, an experiment is designed and implemented to determine the time constant of two thermocouples. In determining the time constant, the recording of the temperature as a function of time is necessary. This is done by using DataStudio software from PASCO together with their temperature sensors. The data acquisition system for PASCO sensors is Data Port, a USB type data acquisition system designed and sold by PASCO. The last experiment is to measure the temperature field across the natural gas flame using a type-K thermocouple. The thermocouple is mounted in a 2-dimensional traverse to collect the data across the flame. The thermocouple is connected to the data acquisition board with LabVIEW software recording the measured temperature values.

The lab for flow measurement contains three parts; calibration of a flow meter using a wet test meter, comparison of three different types of flow meters, and Reynolds pipe flow experiment. All three experiments are not modified from previous arrangements. The lab for humidity consists of two parts; humidity measurement in an enclosure, and demonstration of three psychrometric processes in a chamber. The second experiment is a new setup, designed and implemented by a group of senior students as their senior design project. The project was supported by 2004 ASHRAE Senior Design Grant. In this setup, three psychrometric processes, heating, humidification, and cooling and dehumidification, are arranged in series in a rectangular chamber. The properties of air are determined before and after each process by measuring relative humidity and dry bulb temperature. Both mass and energy balances are performed for each process to evaluate the effectiveness of the process. For all the labs discussed above, calibration experiments are implemented as much as possible for each lab to emphasize the importance of calibration.

The lab for strain measurement is also a completely new experiment. It is implemented as there is not a single lab on mechanical design previously. It is divided into two parts: mounting of a strain gage, and determination of Young's Modulus of three different materials from strain measurement. The strain gage mounting kits from Vishay Measurement Group are acquired together with strain gage kits and mounting manuals. Each group of student is required to mount a strain gage on an aluminum bar and test the wire connection of the strain gage in the cantilever beam arrangement. Strain is measured by P350 Strain Indicator with P110 Strain Gage Connector Block, both from Vishay Measurement Group. Each beam is mounted as a cantilever

beam and loaded at the free end. The strain is measured by strain gage mounted on the beam in either a quarter bridge or a half bridge configuration. The students are required to apply linear regression to the experimental data and determine the Young's Modulus of the beam material. The experiment is repeated for the other two beams. This experiment makes use of the statistics and data analysis topics covered in class to obtain the experimental values of Young's Modulus.

In addition to the strain lab, a new lab on the topics of data acquisition and data analysis and responses of first and second order systems are developed. In this lab, students are introduced to the use of oscilloscopes, frequency counters, filters (low-pass, high-pass, and band-pass), and signal generators to acquire and process digital signals. Then, the responses of first and second order systems are demonstrated by acquiring and processing signals from thermocouples (first order system), strain gages, and accelerometers (second order systems). The students have also learned the use of Fast Fourier Transform (FFT) in studying time varying signals in frequency domain.

Group Projects

Individual lab experiments in the course are tailored to conduct within a certain time frame, thereby providing students with only limited interactions and exploration regarding the lab. As a result, they typically serve to demonstrate the concepts covered in the text while students have little chance of applying the theoretical principles into practice during the lab session. As a result, group projects are assigned to the students during the course to provide them with ample experience in designing, implementing, and conducting their group experiment. Each group is required to prepare a technical report on the group project that contains the list of equipment, experimental procedure, experimental data and interpretations, error analysis, and discussion on the experience of completing the group project. In addition, the use of group projects in engineering provides cooperative learning environment for students to gain useful skills in teamwork and project management. Thus, a group project is assigned to the students in the second week of the course. In the Spring semester of 2005, five projects were assigned:

- (a) Two- and three-point bending
- (b) Characteristics of a solar cell
- (c) Retrofitting the vapor compression refrigeration system
- (d) In-cylinder pressure measurement of a motored engine
- (e) Terminal velocity of a falling sphere

The projects were chosen so as to cover as many different areas as possible; at the same time, the scope of each project was limited so that the group could complete the project in a semester spending about three hours every two weeks when the lab was not in session.

The first project, two- and three-point bending, dealt with mechanical design that involved designing a fixture for conducting two- and three-point bending tests of a beam. This project demonstrated applications of stress measurement in the mechanical design classes and use of strain gages to measure the strain. The students mounted a number of strain gages on a steel beam. Then, measurements were conducted under a series of loading with a strain gage to measure the strain and a dial gage to measure the deflection. The measured values were then

compared with the theoretical values to validate the experiment. A three-point bending set-up was shown in Fig. 1.

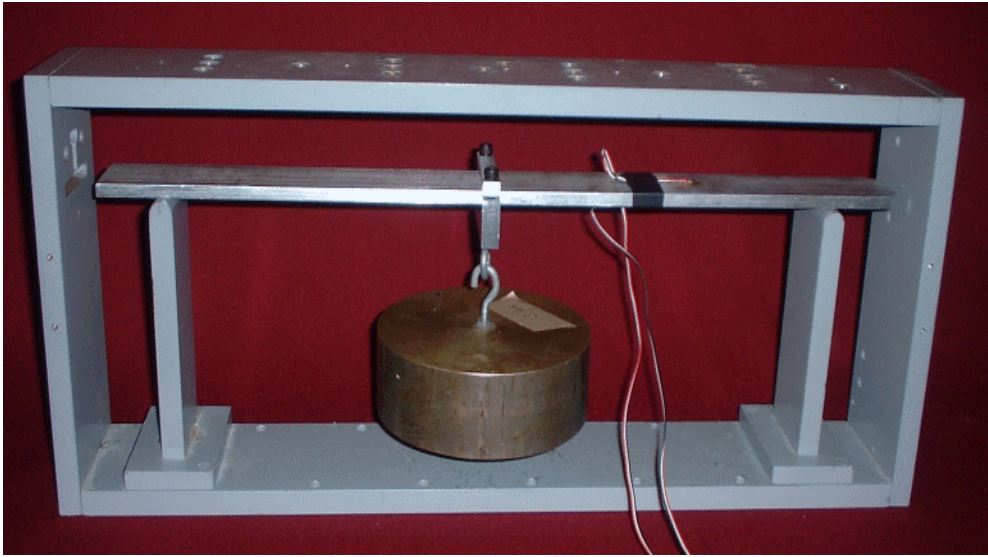


Fig. 1 A Photo of the 3-Point Bending Test Stand with a Beam and a Weight

The second project, characteristics of a solar cell, was related to renewable energy that required the students to experimentally acquire the operating characteristics of a solar (photovoltaic) cell. A photovoltaic panel, Shell SM 55 with 55 W rated capacity, and a solar meter were provided to the students. The students designed and implemented an electrical circuit to test the solar cell under varying loads and would be able to measure voltage and current for each load condition. For a known solar insolation measured by the solar meter, the students measured voltage and current corresponding to the load. Using these measurements the students were able to generate the characteristic curve of the given solar cell and then compared it with the curve provided by the manufacturer. The experimental characteristic curve obtained by the students and the one given by the manufacturer were shown in Fig. 2 below.

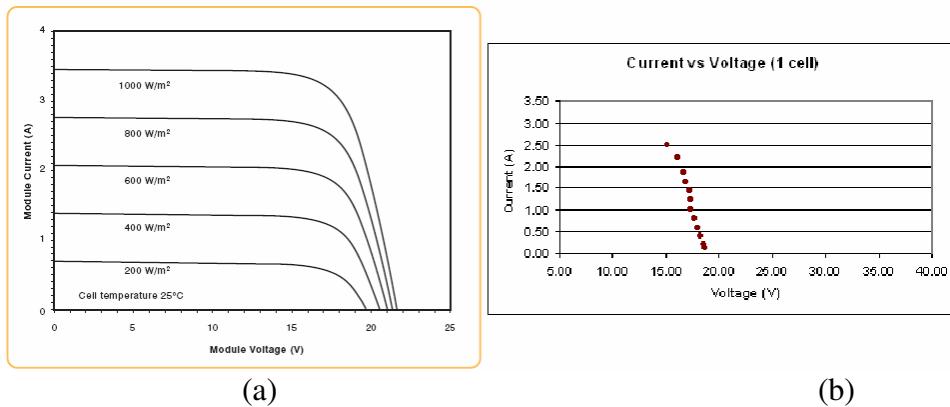


Fig. 2 Comparison of Manufacturer's (a) and Experimental (b) Characteristic of a Solar Cell

The next project, retrofitting the vapor compression refrigeration system, was related to thermodynamics where an existing refrigeration experiment was retrofitted with a new flow meter and the whole system was tested for its performance. The refrigeration experiment was designed and built by a group of students as their senior design project using ASHRAE Senior Design Grant in 2003. The original flow meter in the experiment was not rated properly for the system and therefore the system was not operational at the beginning of the semester. The group of students from this class therefore resized the flow meter, acquired the new flow meter, and made the experiment operational. The group tested the whole system (Fig. 3) and provided the experimental data in their report together with procedure for conducting the experiments for future students.



Fig. 3 A Photo of the Vapor Compression Refrigeration Test Stand

The fourth project, in-cylinder pressure measurement of a motored engine, involved an internal combustion engine where the students were asked to measure the pressure inside the cylinder of a motored engine. The engine was a 8-hp Briggs and Stratton engine used in previous Mini-Baja competition. The pressure sensor, PCB Model 106B, was provided to the students. Initially, the pressure sensor was intended to mount on the existing spark plug port. However, the students found out that the spark plug thread was not compatible with the connecting thread of the pressure sensor. As a result, the students had to make a new fitting so that the pressure sensor could be mounted to the spark plug port. A magnetic pick-up was used to measure the position of the piston. Once the pressure sensor was mounted, the group used the LabVIEW software to acquire the pressure data as a function of time. The output of the pressure sensor was also connected to the scope to check the validity of the pressure trace.

The last project, terminal velocity of a falling sphere, was related to fluid mechanics where the terminal velocity of a falling sphere in a fluid was measured. The ultimate goal of the experiment

was to determine the fluid viscosity from the measured terminal velocity of the sphere in a given fluid. The students built a test stand consisting of a Plexiglas tube of 5 ft length (for visualization) marked with a scale. The main problem for the students was to choose the appropriate combination of fluid and the sphere (material and size) so that the terminal velocity could be measured within the length of the tube. The students chose water as their fluid and stainless steel balls from ball bearings were used as spheres. A single sphere was dropped from the open end of the tube. The distance the ball traveled and the time taken were measured and the terminal velocity was computed. Based on the terminal velocity, the viscosity of the fluid, in this case water, was determined experimentally and then compared with the value from a standard textbook to validate the experiment.

From the discussions above, it could be seen that the group projects were on a variety of topics such as thermodynamics, fluid mechanics, and mechanical design. At the end of the semester, the students were required to write a report and present their project results in class. According to students, the group projects and presentations were very beneficial as they were exposed to many practical applications and implementations of measurement systems involving real-world engineering problems and topics. The added benefit of these projects to the department was that these projects provided additional laboratory experiments that could be used in the future offerings of the course.

Course Resources

Many resources were utilized in the process of revamping the course. Technical writing and presentation were an integral part of the course, therefore, the use of technical writing by Finkelstein as a reference. In addition to the book, the power point presentations on technical writing and presentation developed by Michael Alley of Virginia Tech were of invaluable help. These presentations can be requested by sending email directly to Michael Alley (alley@vt.edu)⁷ who is the author of the texts, *Craft of Scientific Writing*, and *Craft of Scientific Presentations*. The present author has also used these presentations in many other courses and found them to be extremely useful. The text book by Wheeler and Ganji was very useful in discussing and describing the basic principles of measurement systems, analysis of experimental data, uncertainty analysis, and different types of measuring instruments. The author also made extensive use of manufacturers' catalog in discussing types of instrument and their specifications to demonstrate how to select appropriate instruments for the problem at hand. For example, the catalog of Kistler discusses many different types of pressure sensors, their specifications, and recommended uses for each type of sensor. For the topic of computer-based data acquisition and LabVIEW, the resources from National Instrument (NI) were very valuable. One can download modules dealing with basis of data acquisition, selection of data acquisition systems, and fundamentals of LabVIEW from the company web site (www.ni.com). In developing group projects, the author used the contents of academic resource CD-ROM⁸ from NI that contained detailed description of experiments in many engineering disciplines using LabVIEW software. The CD can be requested from NI web site.

Course Outcomes and Evaluation

The following Table 1 gives the list of the course outcomes, which is a subset of the departmental outcome list, outcomes (a) through (q).

Table 1 Course Outcomes of MEEN 3210 Measurements Lab

Outcome	Description
(a)	an ability to apply knowledge of mathematics, science and engineering
(b)	ability to design and conduct experiments, as well as to analyze and interpret data
(d)	an ability to identify, formulate and solve engineering problems
(f)	an ability to communicate effectively
(i)	A knowledge of contemporary issues
(j)	an ability to use the techniques, skills and modern engineering tools necessary for engineering practice
(m)	an ability to use statistics and linear algebra
(o)	an ability to work effectively as team members in mechanical engineering projects
(p)	a knowledge of manufacturing, maintenance and inspections for engineering systems

Among the outcomes listed in Table 1, the most important outcomes for this class were outcomes (b) and (f) with other outcomes being of secondary importance. In order to evaluate whether the outcomes were achieved in the course, students were surveyed at the end of the course. Table 2 was the student survey form used to evaluate the course outcomes.

Table 2 Outcome Survey Form of MEEN 3210 Measurements Lab

Symbol	Outcome	Rating
(a)	The course has taught me how to apply general principles of mathematics, science and engineering	
(b)	The course has taught me how to design and conduct experiments as well as analyze and interpret data	
(d)	The course has taught me how to identify, formulate and solve engineering problems	
(f)	The course has taught me how to communicate effectively	
(i)	The course has given me the knowledge of contemporary issues in the practice of engineering	
(j)	The course has taught me how to use the techniques, skills and modern engineering tools needed for engineering practice	
(m)	The course has helped me to get familiar with statistics and linear algebra required by engineering jobs	
(o)	The course has taught me how to work effectively as a team member in mechanical engineering projects	
(p)	The course has given me an introductory knowledge of manufacturing processes and inspection methods	

Please rate each outcome in the table according to:

5 = very well

2 = moderately well

4 = well

1 = not well

3 = adequately

The analysis and results of student survey from 2005 Spring semester were given in Fig.7 below.

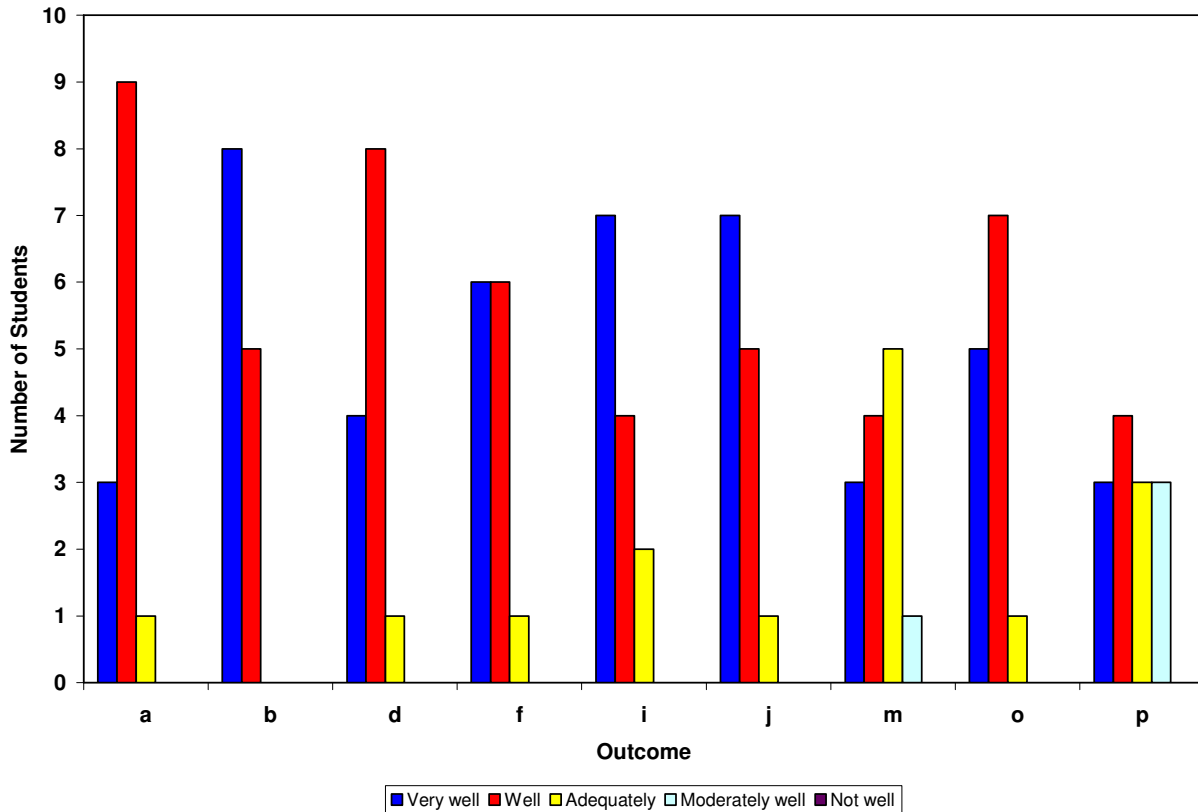


Fig. 4 Outcome Survey Results of Measurements Lab Class Spring 2005

From Fig. 4, it can be seen that the course satisfactorily achieved the major outcomes, outcomes (b) and (f) as all except one student gave well or very well rating for both outcomes. In view of the new materials and experiments as well as group projects, the course outcomes have been revised together with new student questionnaires. The revamped course is being offered in the Spring semester of 2006 and the new outcomes and evaluations will be made available at the end of the semester.

Conclusions

Measurements Lab is a core junior course for mechanical engineering majors in the Department of Mechanical Engineering at Lamar University. In order to modernize the course contents and laboratory experiments, significant changes were implemented for the course. This paper described the course changes in details including description of new experiments and group projects, course outcomes and course evaluations.

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