Virtual Laboratory Development for Undergraduate Engineering Courses

Bret P. Van Poppel, Michael J. Benson, P.E., Daisie D. Boettner, Ph. D., A. Özer, Arnas, Ph. D., P.E.
Department of Civil and Mechanical Engineering
United States Military Academy
West Point, New York 10996 USA

Abstract - *The mechanical engineering program at the United States Military Academy (USMA) has recently explored virtual laboratories for its undergraduate thermodynamics course to complement—or someday replace—existing full-scale laboratory equipment. During the fall term 2003, mechanical engineering faculty developed a virtual gas turbine laboratory and offered a fully digital virtual laboratory exercise in the undergraduate thermodynamics course. By digitally reproducing the laboratory setup, introduction, instrumentation, data collection and analysis, the virtual experience captured the essence of the laboratory. This paper explores virtual laboratory development and future opportunities for virtual educational events. Results of the first version of the USMA Virtual Gas Turbine Laboratory and details of its development are provided.*

I. INTRODUCTION

Faculty members in the Department of Civil and Mechanical Engineering at the United States Military Academy (USMA) created a virtual gas turbine laboratory to overcome some devastating results of weather at West Point during the summer of 2003. Deteriorated building conditions rendered the test cell facility unusable for classroom instruction and the time required to move the engines to a new facility exceeded the time available for the laboratory technicians. Rather than cancel an outstanding educational opportunity, several instructors developed a virtual laboratory. Course faculty offered the USMA Virtual Gas Turbine Laboratory to some sections of the thermodynamics course during the 2003 fall academic term.

As today's laboratories require upkeep and modern equipment, a general lack of resources will soon increase the challenge of continued operation of expensive laboratory equipment. Creating cost-effective virtual laboratories before that occurs is a reasonable precaution [1]. Some institutions already have created virtual laboratory events. Many of these laboratories are web-based applets and programs, and some are completely artificial. The USMA virtual laboratory, by contrast, can be classified as a recorded laboratory in which students work with data from an actual engine [2]. When offered in 2003, the USMA Virtual Gas Turbine Laboratory succeeded in replicating an actual gas turbine engine and achieved all of the learning objectives of the real laboratory. Even though there are components to this virtual laboratory that can be improved, gas turbine education and the laboratory experience reached a new milestone at USMA in 2003.

Since all undergraduate programs do not have the luxury of maintaining laboratory equipment, this experience with virtual laboratory development offers a starting point for other programs that seek to create or revise virtual educational events. While the tremendous advantage of actually seeing, testing, and analyzing the real equipment cannot be denied, a well-planned and executed virtual event can adequately achieve learning objectives and provide students a unique opportunity to apply fundamentals. It is conceivable that future virtual events could offer more opportunities than real ones. The USMA Virtual Gas Turbine Laboratory and the details of its development process are offered as small contributions to the pursuit of future virtual educational events.

II. THERMODYNAMICS AT USMA

The thermodynamics course at USMA offers cadets—future Army officers—a one-semester investigation of principles of thermodynamics. Thermodynamics is presented in four blocks of instruction: Block I - Fundamental Principles; Block II - Carnot Cycle and the 2nd Law of Thermodynamics; Block III - Gas Power Cycles; and Block IV - Vapor Cycles and Air Conditioning. The course has recently been modified to accommodate only engineering majors—prior to the 2003-2004 academic year, the course was offered to engineering majors as well as cadets taking a required five-course engineering sequence.

With only a single semester to present the material, topics must be carefully chosen so the cadet experience is broad enough to understand the many applications of Thermodynamics and deep enough that engineering majors gain the necessary experience to be competent engineers. Gas turbines represent an important concept in this course, covering nearly 10% of the semester. Cadets will encounter several applications of gas turbines after graduating and entering the Army, including engines found on helicopters, tanks, and other platforms [3].

III. The 'Real' Gas Turbine Laboratory

All cadets conduct a 'hands-on' gas turbine laboratory as part of the thermodynamics course. They conduct a two hour laboratory taking measurements on a T-62T-40-1 gas turbine engine, the auxiliary power unit on the Army's UH-60 Blackhawk helicopter. Prior to coming to the laboratory, cadets complete a pre-laboratory assignment that familiarizes them with the APU. They understand where this engine is used and why it is needed. The pre-laboratory also has the cadets compare the ideal Brayton cycle with an actual gas turbine cycle. To prepare cadets to collect and analyze data, the pre-laboratory requires cadets to determine the types of sensors and their respective locations on the engine. After completing the pre-laboratory exercise, the cadets are better prepared to make efficient use of the two hours available during the laboratory [4].

When they come to the laboratory, cadets are introduced to general gas turbine design. Instructors use an easy-to-disassemble Mars gas turbine to review how these engines work. Shown in Figure 1, the Mars engine served as the fire fighting pump for many Navy vessels in the 1950's.

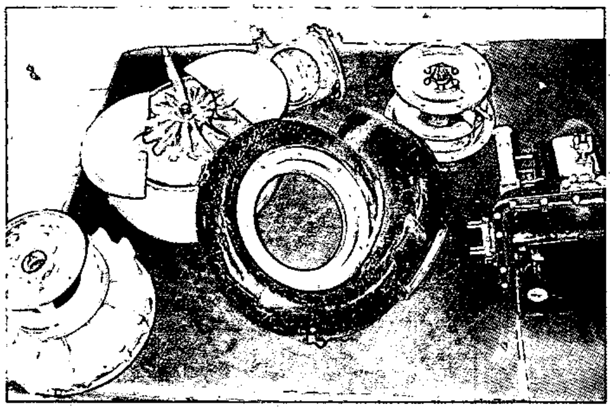

Figure 1
MARS GAS TURBINE ENGINE

Prior to the laboratory, students have seen some gas turbine components and studied the Brayton cycle in class. By disassembling a gas turbine cadets are able to apply what they know about the engines to "reverse-engineer" the device. Instructors help them through the process of determining where the nozzle and diffuser are positioned, how the turbine drives the compressor, and how the engine ignition and self-sustaining combustion occurs. While disassembling this gas turbine engine, cadets realize that one of the advantages of gas turbines is the simplicity of the engine. They understand that the engine in their car could never be disassembled as easily as the Mars engine.

The T-62T-40-1 engine shown in Figure 2 is the engine used in the gas turbine laboratory. Large poster boards show an exploded view of the engine, Figure 3, which help some cadets bridge the intellectual gap between cycle analysis and the actual engine they see in the laboratory.

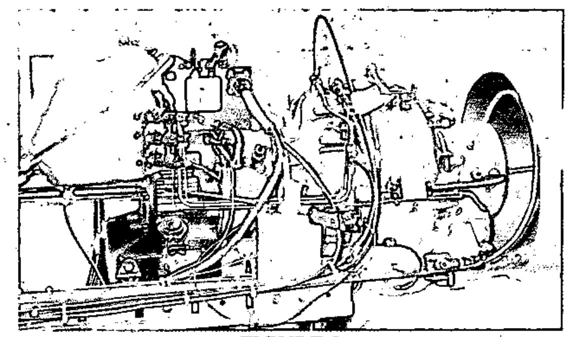

FIGURE 2
T-62T-40-1 GAS TURBINE ENGINE (APU FROM UH-60 BLACKHAWK HELICOPTER)

Around the test stand, cadets learn where temperature and pressure sensors are located and why. They learn how a water-jacket dynamometer works and how to use it to determine the power the gas turbine is producing. After discussing additional topics such as how the pilots start the engine and other functions of the auxiliary power unit, data collection begins. When these engines are turned on, cadets sense, perhaps for the first time, how much power the engine produces when they observe this relatively small auxiliary power unit roaring inside the test cell.

Once inlet, compressor, and exit temperatures, compressor exit pressure, engine torque and RPM data for four experimental runs are collected, the cadets use the remainder of their two hours completing a report. They answer questions requiring the use of the 1st and 2nd Laws of Thermodynamics, isentropic relations, isentropic efficiencies, thermal efficiencies, and the ideal gas equation of state. The cadets are asked to discuss their results. For example, the temperature in the combustion chamber can be calculated with

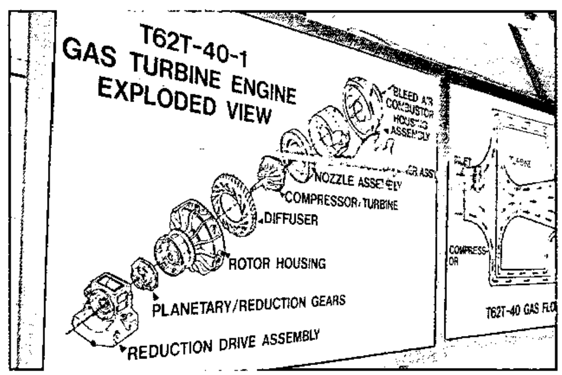

FIGURE 3
EXPLODED VIEW OF AUXILIARY POWER UNIT

the first law across the compressor or with the first law across the turbine. These calculations yield slightly different results and the laboratory report requires cadets to analyze this difference. Cadets determine what assumptions were used for each calculation and their impact on theoretical performance calculations. By the conclusion of the laboratory, cadets have a good appreciation for gas turbines. They now understand basic principles associated with gas turbine engines, identify advantages and disadvantages, and have enough rudimentary knowledge to set up a similar experiment to obtain data necessary to analyze a gas turbine engine.

IV. The Virtual Laboratory Experience

The virtual laboratory experience consists of a pre-laboratory module, a laboratory data collection module, a laboratory report, and a feedback survey. The pre-laboratory module and the laboratory report each include a learning and evaluation component worth 30% and 60% of the laboratory grade, respectively. Completion of a feedback survey accounts for the remaining 10% of the grade.

One of the primary objectives of the laboratory is students' understanding military applications of gas turbine. The course faculty also expect students to understand the design of the experiment, to conduct gas turbine analysis of performance characteristics using the Brayton Cycle model, and to prepare a professional report as additional outcomes included in the virtual laboratory. *It was not an objective to create a virtual reality laboratory in which students could manipulate the engine performance remotely, as might be possible if the laboratory were merely a software simulation or computer program.*

The pre-laboratory experience consists of a 15 minute video and a graded exercise. After watching the video, students complete the graded pre-laboratory exercise electronically. The module utilized multiple choice questions with diagrams and pictures linked to the question as appropriate. Success with the pre-laboratory requirements requires a level of preparation such that students come to the classroom and smoothly conduct the remainder of the virtual laboratory.

Upon arriving in class, the cadets, already arranged into 3-4 person groups, view the virtual laboratory. This video is approximately 11 minutes long, and two separate versions were created so that different data sets could be used for different classes.

After the review, the laboratory video shows the engine start. The video displays a full view of the engine and highlights key engine components and instrumentation. Moving to the data panel, the video identifies each of the data display devices. The dynamometer output display is shown as an example in Figure 4. Following a brief pause to allow cadets to prepare for data collection, four experimental runs are conducted, as in the actual laboratory. Each run differs as laboratory technicians adjust the dynamometer to reach a distinct engine load. World-wide web links to the pre-laboratory and the data recording modules are currently available at the following web addresses:

http://www.usma.edu/asx/CME_ME301.asx
http://www.usma.edu/asx/CME_ME301b.asx
http://www.usma.edu/asx/CME_ME301c.asx

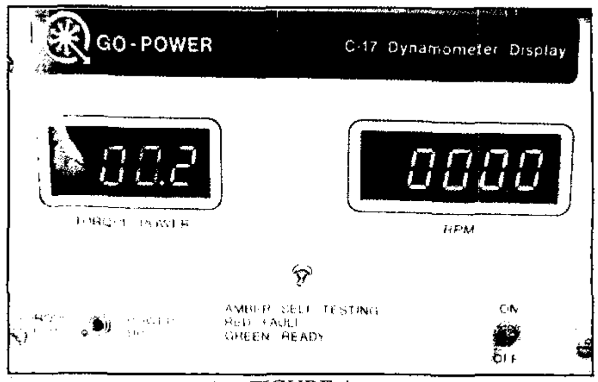

FIGURE 4
DATA DISPLAY DURING THE LABORATORY DATA MODULE

With recorded experimental data, students spend the next 80 minutes of the laboratory performing the same required calculations and answering a variety of discussion-oriented questions as those students taking the 'real' laboratory. The virtual laboratory encourages students to leverage the technological resources available to them during this portion of the exercise (spreadsheets, internet, and mathematics software). Upon completion of their work, students digitally submit their laboratory reports.

Initial Results: Fall Term, 2003

Cadets from four sections (approximately 60 students) participated in the virtual gas turbine laboratory in the 2003 fall academic term. For comparison, another four sections participated in the real gas turbine laboratory (following some temporary building repairs). Instructors made minor adjustments between sections on subsequent days to better present the virtual experience for cadets. While carefully planned and coordinated; the virtual laboratory was challenged with some minor technical difficulties such as sound and computing equipment. Notwithstanding these minor challenges, most students and faculty members agreed that the first version of the USMA Virtual Gas Turbine Laboratory was a worthwhile and beneficial course event. Furthermore, many of the 12 students who volunteered to complete both virtual and real laboratories indicated that the virtual pre-laboratory experience was superior to the real pre-laboratory experience. A few cadets suggested that virtual laboratory assets used in conjunction with real laboratory equipment may be an ideal compromise for programs that maintain both types of laboratory assets. Cadet responses to the feedback survey for the Fall Term, 2003 are summarized in Table 1.

TABLE I
CADET SURVEY AND RESPONSE SUMMARY

Question	Responses
The pre-laboratory exercise reinforces your understanding of the basic principles so that the actual laboratory makes good sense. Did the virtual pre-laboratory exercise prepare you well, or poorly for the final laboratory exercise?	50%: Partially well 50%: Not well
This laboratory environment was significantly different than the two previous laboratories thus far in the course. Was this laboratory easier to comprehend or more difficult to comprehend as a result of this new format?	67%: Reasonably Easy 33%: Slightly Difficult
The success of the pre-laboratory and laboratory hinged on your access to the instructions, video files, and documents incorporated in the event. Rate your access to these files.	75%: Easy access 25%: Difficult access
Physical understanding of laboratory and experimental procedures is a critical learning objective at USMA. Rate how well you feel you understand the instrumentation (thermocouples, transducers, dynamometer, etc.) used in this virtual gas turbine laboratory.	67%: Understood fairly well 33%: Understood poorly
Was the laboratory experience well organized?	67%: Well organized 33%: Fairly well organized

V. VIRTUAL LABORATORY DEVELOPMENT

A laboratory development team, consisting of several instructors and support technicians, expended significant time, effort and technological resources to develop the USMA Virtual Gas Turbine Laboratory. The result was a product that accurately replicated the real laboratory experience for cadets in 2003. The following sections and Table 1 summarize the process used to develop the USMA Virtual Gas Turbine Laboratory.

Laboratory Objectives

To begin development of the virtual laboratory, course faculty first reviewed the objectives of the real laboratory. Even though the learning objectives for both laboratories were nearly identical, the development team investigated how to most accurately *achieve* these objectives in a virtual environment. In particular, developers strived to create an environment that would allow students to use sensory awareness—their human senses—to familiarize themselves with the equipment and instrumentation, to collect data, and to assess operating conditions in a virtual environment [5]. The objectives of the virtual laboratory were:

1. Conduct experimental tests on a gas turbine engine and collect performance data
2. Determine experimental engine performance characteristics
3. Determine theoretical engine performance characteristics using the Brayton cycle model
4. Compare experimental and theoretical engine performance characteristics
5. Describe military applications of gas turbine

Student Requirements

To aid in organizing the total virtual laboratory exercise, the development team identified student requirements—both actions and products—using the laboratory objectives as a guide. Specifically, this laboratory required students to:

a. Review in-class theory
b. Become familiar with the engine and instrumentation
c. Complete a graded Pre-Laboratory exercise
d. Collect and analyze data
e. Prepare and submit a laboratory report

Student requirements a - c above were organized into a pre-laboratory module; the laboratory data collection module comprised student requirements d – e.

Data Collection: The Essence of the Laboratory

The laboratory development team created the data collection module to support the laboratory objectives and provide data for analysis. Course faculty and audio-visual technicians produced one video to display the laboratory instrumentation and locations and the data panel. Additional videos displayed the engine startup and data for each instrument from the data panel. The laboratory development team produced two distinct data collection videos—each corresponding to different engine operating conditions—so different classes could use different experimental data sets.

USMA's Directorate of Information Management (DOIM) provided audio-visual and network support for preparation and filming. Laboratory developers created scripts and "shot lists" detailing every scene of the data collection videos. With the help of the audio-visual technicians at DOIM, developers crafted several scenes to adequately reproduce the sights and sounds of the engine in operation. In particular, one scene portrayed the engine startup with accompanying audio so cadets could hear the peculiar change in pitch when the engine's "light-off" occurred.

Preparatory Resources

With the laboratory data collection built, the development team worked to prepare cadets for the laboratory exercise. The team created a pre-laboratory module to review theory and acquaint cadets with the engine. The pre-laboratory module video included a review of gas turbine fundamentals and governing equations, disassembly of a gas turbine engine, and a graded exercise. The development team also created a PowerPoint presentation to review cold air standard Brayton cycle analysis, to list applications of gas turbines, and to introduce specifications of the T-62T-40-1 engine.

To demonstrate the simplicity of a gas turbine engine, an audio-visual technician filmed a laboratory technician disassembling the MARS gas turbine engine. DOIM technicians produced a high-quality pre-laboratory video that combined the PowerPoint slides and the MARS disassembly with voice-over narration. Cadets could view the video online from their rooms and complete the graded, multiple-choice pre-laboratory exercise. The development team prepared another PowerPoint presentation to summarize much of the pre-laboratory video. During the data collection module, cadets could access the summary presentation to review engine components, instrumentation locations, or Brayton cycle theory.

Module Integration

The Blackboard learning system integrated all modules into a virtual laboratory package. For the virtual laboratory offered in 2003, cadets viewed the pre-laboratory video and completed the graded exercise prior to attending the virtual laboratory. Blackboard allowed the course director or course instructors to control access to the pre-laboratory and graded exercises Additionally, Blackboard automatically graded the exercise and submitted scores directly to a networked grade book. Blackboard accepted laboratory reports and placed them into online folders for instructors to download and grade. After submitting reports, cadets accessed Blackboard again to complete the feedback survey.

The Blackboard administrator devised a 'Test Course' for the development team to rehearse the laboratory and identify and correct any technical issues before administering the virtual laboratory for cadets. The development team set permissions for several other faculty members in the department to access the pre-laboratory module and data collection videos. The Test Course rehearsal was very beneficial in forestalling many technical and integration issues prior to the virtual laboratory.

Resource Requirements

It is somewhat difficult to identify the 'exact 'costs' associated with the development of this laboratory. In terms of time, instructors spent over 60 hours just on video development and setup. Computer support requirements included the laptop computers, wireless network, Blackboard system, and Academy server space for the streaming web-video, in addition to the personnel and technicians already mentioned. However, these computer support facilities already exist at USMA (and probably at most other educational institution). The film crews provided significant expertise and support throughout the production and editing process, and their tapes, lights, and labor cost the department about $1300.

Once complete, however, repeated instances of the laboratory create no new expenses, quite unlike the operation of the real laboratory which requires technical support, maintenance, fuel, and upkeep to continue operations.

VI. Future Development

The first version of the USMA Virtual Gas Turbine Laboratory was a product that many mechanical engineering programs could produce—essentially the laboratory was a filmed version of the engine in operation. The next version of the virtual gas turbine laboratory will include many significant revisions. It will be a multidisciplinary package that strives to exceed the opportunities offered by the real gas turbine laboratory. The second version will be developed in conjunction with computer science faculty members from the Department of Electrical Engineering and Computer Science at USMA and should be available for the 2005 fall academic term.

The next version of the virtual gas turbine laboratory will focus on the pedagogy of *design of experiment*. Rather than executing a pre-existing experimental procedure, cadets will make a hypothesis, select relevant performance parameters, and set appropriate engine operating conditions to collect necessary data. A laboratory that incorporates such flexibility would be impractical or impossible to conduct in a real laboratory setting. Some specific examples of future experiments include:

- Torque, horsepower, and fuel efficiency at various engine operating speeds
- Engine noise and emissions at various fuel flow rates
- Air flow rates at various engine operating conditions
- Effects of altitude and engine aircraft speed on performance

The virtual laboratory development team will integrate the interactive component by incorporating laboratory instruments into a platform such as LabVIEW [6]. To achieve this integration, the mechanical engineering program will provide the operational laboratory video and computer science faculty members will develop the software platform that allows cadets to control engine parameters and operating conditions.

The mechanical engineering program at USMA will also investigate virtual forms of other existing laboratories, such as a Steam Turbine Laboratory, Spark Ignition Engine and Compression Ignition Engine Comparison Laboratory, and Comparative Fuel Research (CFR) Laboratory. Additionally, the faculty here will explore virtual events for new and developing technologies for which we have no laboratory experience.

Future possibilities include military jet applications, solar or wind energy facilities, and nuclear power facilities.

VII. Conclusions

Some academic institutions may have instrumented gas turbine engines to conduct experiments for undergraduate students. Regardless, these existing undergraduate laboratories could maintain a virtual laboratory as a ready and easily implemented contingency in case of mechanical or other difficulty. For schools that do not maintain a gas turbine laboratory, the option of a virtual laboratory could be a viable alternative laboratory experience to reinforce gas turbine fundamentals.

For some students, a virtual experience may never fully replace the hands-on experience of a real laboratory. The effectiveness of any virtual educational tool depends upon its ability to adequately replicate a "live" experience. With some refinement, virtual events like the USMA Virtual Gas Turbine Laboratory can close the existing gap between "live" and virtual experiences. As instructional technologies continue to develop, it is foreseeable that virtual events could someday be more effective educational tools than real ones, and the pedagogical considerations inherent in this process deserve significant attention [7]. Achieving this end will require virtual developers to genuinely *leverage* instructional technology, not just use it to provide traditional content in a convenient and easily accessible format. Progress in the area of virtual education must be multidisciplinary and will require coordination of various agencies, substantial effort, and successful integration of multiple technologies. This paper offers the details of this process as a small contribution to future development of virtual educational events.

TABLE 2
VIRTUAL LABORATORY OBJECTIVES AND REQUIREMENTS

	Pre-Laboratory Module	Data Collection Module	Report Submission	Feedback Survey
Objectives	• Review Gas Turbine fundamentals	• Familiarize students with test stand and instrumentation • Collect data	• Conduct experiment and theoretical analysis of the gas turbine engine • Prepare a laboratory report	• Provide feedback on effectiveness of the virtual laboratory experience
Student Requirements	• Watch Pre-laboratory video • Complete pre-laboratory graded exercise	• Watch laboratory video • Collect all relevant data points for four experimental runs	• Calculate engine performance parameters using experimental data • Calculate theoretical engine performance parameters • Submit a laboratory report	• Complete web-based survey
Equipment Requirement	• Network and server space for web-streaming video (DVD for backup) • Computer capable of playing video and accompanying audio • Networked instructional technology (e.g., BLACKBOARD) for graded online exercise	• Network and server space for web-streaming video (DVD for backup) • Computer capable of playing video and accompanying audio	• Networked instructional technology (e.g., BLACKBOARD) for online submission of lab report	• Networked instructional technology (e.g., BLACKBOARD) for online survey

VIII. ACKNOWLEDGEMENT

The views expressed herein are those of the authors and do not purport to reflect the position of the United States Military Academy, the Department of the Army, or the Department of Defense.

REFERENCES

[1] Swain, N., and Anderson, J., "Application of Graphical Programming, Object Oriented Programming, and Virtual Instruments in Education." http://www.cs.utep.edu/chitta/hmcs/cit99.swain.doc.

[2] Peeyush, B. et al. "Virtual Labs, Real Data for Statics and Mechanics of Materials." 2003 ASEE Annual Conference and Exhibition, Nashville, Tennessee, June, 2003.

[3] Albert, B., Arnas, Ö, Bailey, M., Klawunder, S., Klegka, J., Wolons, D., 2001, "A Unique Approach to Teaching Thermodynamics," Proceedings, ECOS '01, Istanbul, Turkey, Vol. 1, pp. 181-193

[4] Benson, M., Van Poppel, B., Boettner, D., Arnas, O. "A Virtual Gas Turbine Laboratory for an Undergraduate Thermodynamics Course." GT2004-53489, 2004 ASME Turbo Expo, Vienna, Austria, June, 2004

[5] Feisel, L. and Peterson, G., "A Colloquy on Learning Objectives for Engineering Education Laboratories." 2002 ASEE Annual Conference and Exhibition, Montreal, Canada, June, 2002.

[6] Barker, Philip, 1994. "Use of a Virtual Laboratory for Teaching Instrument Design." IEE Colloquium, 5(1-5)

[7] Johnson, W. L. (1995). "Pedagogical agents in virtual learning environments." Proceedings of the ICCE 95: International Conference on Computers in Education, (41-48)