Mastery Learning as a Teaching Methodology in Engineering Graphics

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Abstract

Mastery learning has been utilized successfully in education in such fields as English, Mathematics, Physical Education, and Science. Mastery learning is defined as the "attainment of adequate levels of performance on tests that measure specific learning tasks" [5]. The Engineering Graphics Technology Department at Oklahoma State University in Okmulgee has utilized various forms of mastery learning for the teaching of engineering graphics, drafting, and computer aided design. This paper describes how this department has incorporated mastery learning into its curriculum. Included in this paper will be background information on the theory of mastery learning and the Engineering Graphics Technology Department's utilization of this theory in its courses. Additionally, qualitative feedback from students will be explored.

I. Introduction

From the first day of employment, industry places demands on technology graduates to be productive. New technicians and engineers have to be literate in applications and technologies in order to be successful in the world of work. In today's competitive world, companies cannot afford new employees that do not meet minimum standards. Educational institutions have to graduate students who strive to meet high standards and who are proficient in the technological skills required of their job.

Many educational methodologies have been employed for the teaching of engineering graphics related courses. Common delivery approaches include demonstration, lecture, and modeling. These methodologies are followed normally in the educational process by hands on application of the subject matter. Hands on application can consist of individual or group assignments tailored around problem-solving activities and/or design activities. Traditionally, the final product of this application exercise is evaluated for its merit and how well it meets a particular standard. As an example, in an architectural design course, students may be given an assignment to design a floor plan for a residential building. Within this project, students may be given criteria for the design and for the project as a whole. When the instructor evaluates the project, it is common to give a grade based on the design and the quality of the work. Occasionally, students are given the option to improve their grade on the assignment.

A problem with the above approach to teaching is that it can allow some students to progress without meeting certain minimum standards. For an architectural project, a student may not properly design a kitchen; for a mechanical drafting assignment, a student may not apply rules of dimensioning correctly. Allowing students to progress without meeting standards can cause several problems. First, students may not learn a particular design standard. Allowing a student

to pass a course in residential design without understanding how to design a kitchen places him or her at risk when entering the job market. Second, students may not have the skills necessary to develop advanced competencies. Not understanding dimensioning fundamentals can lead to more problems when applying tolerances to a drawing, similar to how not knowing algebra can be detrimental to a student taking calculus. Finally, students can become imprinted with the idea that partially meeting a standard is adequate. Employers do not want students that can only meet 90% of the standards expected of them. Educators, like industry, should expect students to be proficient and to meet 100% of all standards.

Is it reasonable to expect all students in a course to meet 100% of all standards? In an ideal world, students would have equal abilities and equal motivations. Since we do not live in an ideal world, it is expected that some students, due to lower abilities, motivation, or other factors, will only achieve to a certain level. It is also common for teachers to progress students through a topic or subject with less than optimal abilities. These less than optimal abilities can be detrimental to future growth, development, and well being. Often, the determining factor on whether to pass a student is the average grade obtained by that student. Determining the outcomes of a course base on an average grade is a common educational practice. According to Torshen [6], averaging is a major cause of problems in education.

There are several reasons why students are allowed to progress in a course while only meeting minimum standards. For one, students learn at different rates. While one student may master a subject in a certain allocated time, a second student may be able to meet only half the requirements in the same length of time. In the case of the latter student, progression in the subject is dependent upon the minimum standards of the course and also upon future success in other topics within the course. Second, most current educational systems place a restriction on the amount of time a student may spend learning a subject matter. A typical three-semester hour algebra course meets about 48 hours. How much a student masters in algebra is dependent upon the length of time spent in the course and the motivation to work outside of class. If a student does not master a topic within the set period of time, future work may be hindered. In addition, traditional educational processes require students to progress through topics of a course at the same rate. In a traditionally taught basic computer-aided design course, an instructor will spend a set amount of time on a topic before moving to a new one. Usually, it does not matter if all students in a course have mastered a topic. Any deficiencies will have to be made up outside of class.

How do graphics educators ensure that all students are given the chance to master a subject? One way to ensure that a student masters a subject is to require of the student nothing less than meeting a prescribed standard. Mastery learning, as an educational philosophy, can provide engineering graphics students with the opportunity and time to master a topic.

II. Mastery Learning Fundamentals

Mastery learning has been utilized successfully in education in fields such as English, Mathematics, Physical Education, and Science. Mastery learning is defined as the “attainment of adequate levels of performance on tests that measure specific learning tasks” [5]. John Carroll [3] was the first individual to develop a formal base for the theory of mastery learning. His

model states that a student's aptitude determines the level at which he or she learns a specific task or the amount of time it takes him or her to reach a specific level. According to Carroll, "no matter what their interest is, or how they are motivated, if they spend the amount of time they need on learning the task, they will learn to criterion" [4]. Typically, education environments do not give all students the opportunity to learn to a criterion. Carroll further states that the length of time required by a student to learn to standard can be affected by the quality of instruction and the student's ability to learn. Poor instruction coupled with a low ability level will increase the time needed to master a subject. In regards to the utilization of mastery learning in the classroom, one student might take a short period of time to master a task while a second student might take longer to master the same task. In the end, both students do master the task at a predetermined level. Additionally, under Carroll's model, if the aptitudes of students in a class are normally distributed and the same instruction is provided to everyone, then the achievement of students will be normally distributed. Also, it is reasonable to state that if instruction is allowed to vary to meet the needs of all students in a course, then the majority of the students will master the subject.

IIa. Mastery Learning Variables

Bloom describes five variables for mastery learning strategies [2]. First, all students vary in their aptitude to learn a task. Carroll views aptitude as the length of time it takes an individual to master a task [3]. Defining aptitude in this matter requires one to assume that, given enough time, all students can learn a task. Applying this variable to an actual classroom setting can be difficult when students in a subject possess a wide range of skills and talents. Taking this into consideration, one can imagine that students at the low end of the aptitude scale may not be able to master a task to the same level as other students in the course. The second variable, quality of instruction, is the degree to which individual students in a group receive the same level of instruction. According to Bloom, educators often believe that high quality instruction is defined as how well a group receives a block of material. Mastery learning concepts define quality of instruction as how well material is received by all individuals. Quality instruction according to one student may not be quality instruction to another. The key is finding an instructional delivery method that will result in worthwhile instruction for all in a group. Closely related to quality of instruction is the third variable, the ability to understand instruction. Bloom defines the ability to understand instruction "as the ability of the learner to understand the nature of the task he is to learn and the procedures he is to follow in its learning" [2]. Two factors come into play under this variable. First, each student has to understand the instructor; second, each student has to understand any instructional materials (books, handouts, etc.) being used in the course.

The final variables as described by Bloom are absolutely critical to the successful implementation of mastery learning. The fourth variable is the perseverance of the student to continue learning. The basic theory behind mastery learning, as defined by Carroll, states that most students can learn to an established level if given enough time. Students have to feel that continued persistence at learning a task will payoff in the long run. Bloom states that perseverance can be increased by rewarding continued successes and by increasing the quality of instruction [2]. The final variable, time allowed for learning, is key also to the successful implementation of mastery learning. Students with higher aptitudes for learning will master a task quicker than students with lower abilities. Most students, though, will master a task if given enough time. An environment has to be established that will provide all students with a

reasonable amount of time to master all tasks required of them. This variable can be difficult to overcome with educational institutions that set time limits for the completion of a course.

IIb. Mastery Learning Assumptions

According to Horton, there are several assumptions that form the foundation for every mastery learning program [5]. For mastery learning to be implemented successfully, each assumption has to be met. The first assumption states that nearly all students can learn equally most standard school tasks. All students have to have the capability to master a subject before mastery learning can be considered a viable educational philosophy. As an example, within a basic technical drawing course, there are several tasks (such as dimensioning and orthographic projection) which an engineering graphics instructor would like his or her students to master. Typically, these tasks are neither difficult intellectually or overly challenging. Due to this, mastery learning would be a good approach. The second assumption requires that a school be student centered. Traditional instructional approaches require each student to adapt to the delivery of an instructor. Research shows that all students do not learn identically. Usually, students with learning styles that match the delivery style of an instructor will be the most successful in a course. Mastery learning approaches to education require instructors to modify instruction to meet the learning styles of all students. Similarly, "mastery learning assumes that if appropriate instruction has been provided, the difference in individual achievement reaches the vanishing point" [5]. The third assumption stipulates that enough time must be provided to assure that all students have the opportunity to master a course. Within a traditional basic engineering graphics course, some students will have more developed visualization abilities. It can be argued that students with less developed visualization skills have a disadvantage in orthographic projection, three-dimensional modeling, and design. These students will require more time to master an engineering graphics task. Enough time has to be provided for each student to master all tasks.

The final three assumptions, as described by Horton, deal with matters of curriculum. First, intellectual differences in students do not determine what is taught in a course. Students in need of remedial work should not drive the instructor to lower the number of tasks taught and the standards for tasks that are taught. Second, subject matter should have clear and measurable objectives. Setting objectives and evaluating them to determine if they have been met is critical to successfully applying mastery learning. The basic approach to mastery learning allows students to progress from a task to a more advanced task upon meeting a prescribed standard for the first task. Students and instructors need to have a way to measure if a prerequisite task has been mastered. The final assumption for mastery learning requires instruction to be sequential and logical. For mastery learning to be utilized properly, building blocks of knowledge and/or skills have to be set before advanced skills can be learned. Courses such as mathematics, physics, and chemistry are good examples of subjects that build upon previously acquired knowledge. Additionally, a physics student would have a hard time mastering most basic problems without good skills in algebra and trigonometry. Also, while high-aptitude students will learn material in the absence of proper sequencing, the lower the aptitude of a student, the more sequencing is critical.

IIc. Mastery Learning Model

As previously stated, mastery learning can be used for a variety of subjects but works best for courses that have sequential topics and measurable objectives. The mastery learning model consists of six components: objectives, preassessment, instruction, diagnostic assessment, prescription, and postassessment.

Properly structured objectives are vital for mastery learning. Objectives represent what the instructor wants the learner to be able to accomplish when completing a course. These objectives should be measurable to a predetermined standard. Bloom's taxonomy is a good tool to use when constructing objectives [1]. Careful analysis of subject matter should reveal objectives that fall within the cognitive, affective, and psychomotor domains. Higher-order objectives should be used when possible but not at the cost of having an objective that is not measurable. Important while developing objectives is establishing a minimum pass level. Many subjects will have nothing less than flawless work as the minimum pass level, but this may not be appropriate for all topics. Many factors should be considered when establishing the minimum pass level. Examples include future academic needs of each student, needs of business and industry, and affective needs (such as safety).

Assessment is used throughout the mastery learning model. Objectives established are tested three times in the mastery learning model: pre-instructional assessment, diagnostic assessment, and postassessment. Preassessment is used to determine beginning levels of students and to help design the most effective instructional delivery mechanism. Postassessment, the last step in the mastery learning model, is used primarily to determine if a student has met the objectives prescribed for him or her. It can also be used to assess instruction and to refine objectives. The third method of assessment, diagnostic, is a formative evaluation technique used to measure the effectiveness of ongoing instruction. It is used to improve the instructional process.

When a diagnostic assessment reveals an instructional need, a prescription is determined to meet this need. A prescription might consist of remedial instruction for a student that is struggling to meet an objective or it may consist of relocation. Relocation allows an instructor to move a student to a new location in the sequence of instruction in order to meet a need of the student. This may take place when it has been determined that a student is not working toward an appropriate objective, when the student needs a review of previous instruction, or when a student is at a higher level of achievement than previously expected.

Instruction is the step in the mastery learning model with the most immediate interest to instructors. There is no prescribed way to deliver instruction in the mastery learning model. Though a variety of techniques may be used, the best approaches allow students to progress at their own pace through each learning objective. Sometimes this can be challenging in educational environments where groups of students traditionally progress together through objectives. Care needs to be taken when developing an instructional strategy to include as many possible learning styles in the instructional approach.

III. Issues Affecting Mastery Learning in Engineering Graphics

Principles of mastery learning have been used successfully in the Engineering Graphics Technology (ENGT) Department at Oklahoma State University in Okmulgee (OSU-Okmulgee). OSU-Okmulgee is the technical branch of Oklahoma State University and offers Associate of Applied Science degrees. Typical programs of study at OSU-Okmulgee require 90 semester hours of credit. The Design Drafting Technology program is located in the ENGT department and utilizes AutoCAD, MicroStation, and Pro/Engineer as its computer-aided design packages. Students are placed in the mechanical, electrical, piping, architectural, and civil industries upon graduation.

Most courses in the ENGT department at OSU-Okmulgee are well suited to a mastery learning approach. These courses are designed typically in a logical, sequential order. Additionally, many of the course objectives are measurable and obtainable by a majority of all engineering graphics students. Despite this, as with most courses at the college level, there are some issues that have affected the implementation of a mastery learning model. The following are ways that faculty in the ENGT department have addressed these issues.

A critical issue affecting the utilization of mastery learning within engineering graphics is the necessity to provide enough time for all students to master an objective. As previously mentioned, an assumption of mastery learning is that most students can meet an objective if given enough time. There is some debate among faculty members if this is possible within all established engineering graphics courses. A course such as basic computer-aided design at OSU-Okmulgee has within its curriculum prescribed objectives. In order to determine if a student should progress to more advanced topics, mastery learning requires these objectives to be measurable. High ability students, as determined by variables such as intelligence, visualization skills, and/or motivation, will meet objectives quicker, it can be argued, than lower ability students. College level courses have set contact hours for credit hours being attempted. A concern with the ENGT department at OSU-Okmulgee is ensuring that a course is rigorous enough to challenge students but flexible enough to allow all students the time to meet prescribed objectives. There is no clear, established way to do this. The solution lies in the creativity of the instructor and his or her ability to incorporate within each lecture a delivery approach conducive to achievement for all learning styles. Possible solutions employed within the ENGT department have included eliminating deadlines, establishing flexible laboratory schedules, arranging for tutors, and allowing incomplete grades.

Mastery learning requires the establishment of measurable objectives. These objectives are used to determine if a student should progress to more advanced material. Due to its nature, many assignments within the ENGT department require the production of images used to portray design information. These images may consist of detail drawings, three-dimensional computer models, prototypes, or manufacturing data. The evaluation of engineering graphics assignments can vary between instructors. In a course, these evaluations may be used to measure how well students are progressing and/or how well instruction was received. Within a mastery learning environment at OSU-Okmulgee, these evaluations are also used to determine if students have mastered course objectives. Establishing objectives that can be evaluated has been challenging for most of the ENGT instructors. Many objectives are subjective in nature, especially on issues related to design (architectural design, industrial design, etc.). For courses with subjective

objectives, mastery learning was not be the best approach. For non-subjective courses, especially those that follow industry standards, mastery learning has been utilized successfully. An example is a course on geometric dimensioning and tolerancing. There are prescribed standards for how to apply geometric tolerances to an engineering drawing. These standards are the basis for establishing the course objectives.

Another concern of the ENGT department at OSU-Okmulgee is determining at what level should students meet a standard? Mastery learning approaches strive for students to meet all standards required of them. Within a basic engineering graphics course, is it acceptable for a student to meet only 75% of the standards provided? The answer to this question depends on several factors. First, would it hurt the student's future growth to allow only minimum standards to be met? Second, are employers expecting the student to know the standards included in the 25% not met? It is possible, in some cases, to allow students the opportunity to select the standards that they want to achieve. They have to be made aware, though, that not meeting all standards could be detrimental to their future.

There are two ways that have been identified by ENGT faculty at OSU-Okmulgee to approach standards and objectives. Most courses have an established number of objectives. Meeting 100% of the standards of a course would require a student to meet 100% of the standards for all objectives within the course. A traditional way to determine a grade for a student would be to average the grades for all assignments in a course. The second way use by ENGT faculty to evaluate students on the meeting of objectives is to count only those objectives in which the student actually meets 100% of the standards. As an example, an introductory engineering graphics course might require a student to complete 10 drawing assignments. These assignments are used to measure certain objectives established for the course. Within this example, if a student meet 100% of the standards on only eight of the objectives but fell short on the remaining two, that student could say that he or she is 100% proficient at those eight objectives.

Another issue affecting the utilization of mastery learning as a teaching philosophy within the ENGT department at OSU-Okmulgee is the setting of minimum pass standards for objectives. The very nature of mastery learning stresses a student mastering an objective before progressing to another. Many courses taught at OSU-Okmulgee are based on industry standards. Standards established by organizations such as the American National Standards Institute (ANSI) are there to improve collaboration, communications, safety, and consistency within the engineering community. As mentioned previously, these standards are used to establish objectives for many of the engineering graphics courses. In most subjects, ENGT faculty members believe that it is vital that students have an understanding of industry specific standards. Faculty members stress these standards within their evaluation of student work.

Should 100% of all standards be meet for an objective? This depends upon the course and the objective. Many topics are so subjective in nature or are not governed by official standards that it would be difficult to say that a product is 100% correct. Many basic engineering graphics courses, though, are well suited to setting the minimum pass level at 100% correct. As an example, the topic of dimensioning within an introductory drafting course would be a good selection for utilizing perfect standards as the minimum pass level. For this topic, a student would be required to modify his or her drawing until it met all established dimensioning

standards. This might require the student to have to modify his or her drawing several times. In the end, the student has worked to and completed an assignment to industry level standards. Is this better than allowing a student to finish at only 80% of industry standards?

According to OSU-Okmulgee's ENGT instructors, the repeated modification of assignments to meet minimum pass levels can cause some problems. First, it places a grading burden upon instructors. Traditional evaluations call for an instructor to grade an assignment once. Mastery learning may require an instructor to have to evaluate one assignment many additional times and in the process have to keep up with previously assigned grades and previously assigned student work. Second, students are required to repeat assignments until they meet the minimum pass level. This can also be a burden to students. Many times, due to additional requirements, a student may decide to take a lower grade in order to have time to work on other assignments and concerns. The mastery learning approach used may not allow this.

IV. Mastery Learning Utilized in Engineering Graphics

Many different forms of mastery learning have been used within OSU-Okmulgee's ENGT department. All courses within the department have established objectives. The primary concern of the ENGT faculty is the mastery of these objectives within a particular course. Objective evaluations are based on each student successfully meeting a minimum pass level. Most minimum pass levels are set to meet 100% of the prescribed industry standard. Objectives are tracked by listing each objective (or assignment) and student on a chart (see Figure 1) and marking each student off on the chart when he or she has successfully met an objective. Charts are displayed in the classroom so students can track their progress. Student names are coded to ensure that unauthorized individuals do not obtain private information.

	EGT 1204 – Computer-Aided Design I COURSE OBJECTIVES																													
STUDENT	OBJ. 1	OBJ. 2	OBJ. 3	OBJ. 4	OBJ. 5	OBJ. 6	OBJ. 7	OBJ. 8	OBJ. 9	OBJ. 10	OBJ. 11	OBJ. 12	OBJ. 13	OBJ. 14	OBJ. 15	OBJ. 16	OBJ. 17	OBJ. 18	OBJ. 19	OBJ. 20	OBJ. 21	OBJ. 22	OBJ. 23	OBJ. 24	OBJ. 25	OBJ. 26	OBJ. 27	OBJ. 28	OBJ. 29	OBJ. 30
Student 1																														
Student 2																														
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Student 4																														
Student 5																														
Student 6																														
Student 7																														
Student 8																														
Student 9																														
Student 10																														
	F												**D**					**C**					**B**					**A**		
	FINAL GRADES BASED ON THE NUMBER OF OBJECTIVES SATISFIED																													

Figure 1. Typical Objective Chart

For most of its courses, the ENGT department uses an advanced-standing examination based on objectives. This examination is given the first week of class and serves several purposes. First, any student scoring a prescribed level on the examination can receive credit for the course and advance to another course. This allows students with previous training to test out of courses in

which they already meet a minimum established level. Second, the advanced standing examination gives instructors a good understanding of the beginning levels of their students. This allows them to tailor a course to meet the changing needs of their students. Third, the advanced standing examination can be given again at the end of the course to produce a gain score for each student and for the class. And finally, the advanced standing evaluation is used as the preassessment tool to help design instruction based on the mastery learning model.

The ENGT department at OSU-Okmulgee is concerned with meeting the individual learning style needs of all engineering graphics students. During the first semester in the program, each student is required to take a battery of tests to recognize his or her personality type and learning style. Each instructor has access to this information to help in modifying instructional strategies. Additionally, student advisors are given this information to counsel students on issues of learning style and personality type.

The first use of mastery learning described in this paper, referred to here as Sequential-Objective/Set-Grade (SOSG), is employed the most frequently within the ENGT department. As shown in figure 1, objectives are established and charted. An advanced standing examination is given to students during the first week of class. Students must work on objectives in a sequential order as dictated by the instructor. Instruction occurs just-in-time to meet the needs of individual students and may take the form of lecture, tutorials, and/or demonstrations. Students must meet minimum pass standards (typically 100% of set standards) for an objective before advancing to the next. There is no set number of times that a student may be evaluated on an objective. The number of objectives met during a semester determines the student's final course grade. Deadlines are not given for objectives. As shown in figure 1, meeting 28 through 30 objectives earns a student a grade of an "A", 23 through 27 earns a "B", 18 through 22 earns a "C", 13 through 17 earns a "D", and if a student meets less than 13 objectives, he or she receives a failure for the course.

A Nonsequential-Objective/Set-Grade (NOSG) approach is similar to the SOSG approach but allows a students to meet objectives in any order desired. In certain courses, objectives may or may not always build upon previous objectives. If objectives do not build upon each other, this approach may have some advantages. Deadlines are set to facilitate a student's work toward all objectives. As with the SOSG approach, course grades are based upon the number of objectives met (see Figure 1).

Number of Attempts	Grade
One	100
Two	90
Three	80
Four	70
Five or More	0

Table One: Objective Grades Based on Number of Attempts

The final mastery technique described in this paper, Nonsequential-Objective/Reducing-Grade (NORG), is a common mastery learning technique. As with the NOSG approach, students may

master objectives in any sequence desired. When compared to the SOSG and NOSG approaches, grade determination is different. Students are required to master objectives but individual grades are reduced for each attempt at meeting an objective. Table 1 shows possible grades for mastering individual objectives based on the number of attempts. Obviously, the more attempts required to meet an objective, the lower a student's grade.

V. Instructional Evaluation

To evaluate the ENGT's mastery learning approaches from a student perspective, focus groups were held. The primary objective of each focus group was to obtain information from students on what they liked about mastery learning and what they did not like.

The consensus opinion from students was favorable toward mastery learning. Most positive comments were centered on grading and objective progression. Students liked having the opportunity to improve their grades and they liked the feedback provided to them by their instructors. Additionally, they liked knowing what it took to receive a specific final grade in a course.

Negative feedback from students centered on the time it took to finish assignments and the grading criteria. Many students were not motivated to work toward mastery on every assignment. Some students felt that they should be allowed individually to make a lower grade on a project. Additionally, some students did not feel comfortable with a new grading system.

VI. Recommendations

Mastery learning principles have been used successfully in education for several decades. Due to its emphasis on the mastery of a subject matter, it has promise for use in engineering and technological education. Despite this, little research has been conducted on the affect that it has in technological disciplines. Formal evaluations of mastery learning compared to traditional educational methodologies should be conducted on issues related to achievement, problem-solving, task persistence, and student attitudes.

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