The Online LaModel User's & Training Manual

Development & Testing

Christopher R. Newman

This Thesis is submitted to the Benjamin Statler College of Engineering and Mineral Resources at West Virginia University in partial fulfillment of the requirements for the degree of

Master of Science in
Mining Engineering

Keith A. Heasley, Ph.D., Chair
Brijes Mishra, Ph.D.
Yi Luo, Ph.D

Department of Mining Engineering

Morgantown, West Virginia
2015

Keywords: LaModel, Displacement-Discontinuity, Boundary-Element, Laminated Overburden

Abstract

The Online LaModel User's and Training Manual: Development & Testing

Christopher R. Newman

In order to better inform and train industry professionals, as well as engineering students and new users, an electronic user's manual and comprehensive online training course for LaModel has been developed in an open online learning environment. The online user's manual provides widespread access to detailed information on the installation, proper use, and troubleshooting procedures through a combination of: written documentation, voiced-over and captioned software simulations and slide presentations, and relevant academic articles. Some of the online LaModel material has also been organized into a set of progressive, self-paced training modules using a number of the slide presentations and software demonstrations, with the addition of pedagogically designed learning activities and proficiency quizzes. These training modules are designed such that a new user can complete the sequence of three learning tracks (novice, intermediate, and advanced) to become a proficient user of the LaModel program.

This thesis reports on the development and implementation of the new LaModel user's manual and training course. Currently, the on-line material includes 84 pages of technical notes and 6 hours of slides and hands-on learning activities. In this thesis, the overall layout and format of the user's manual, training modules, and proficiency quizzes are presented along with samples from specific manual sections and classroom lessons.

With an increase in operational difficulties, geologic intricacies, and regulatory review, this generation of mining engineers require complex analyzes to determine the integrity of underground mine works. Through access to the new online user's manual and training modules, novice LaModel users can be effectively trained on the correct operation and analysis techniques for using the LaModel program, while experienced users can quickly access detailed information on the newer and/or more complex LaModel functions. The development of both the user's manual and online training course will ultimately increase the effectiveness of mining engineers within the industry, leading to more productive and safer mine designs.

Table of Contents

List of Tables

List of Figures

1.0 Introduction

Released in 1993, LaModel (pronounced *Lam-model*) has aided mining engineers and researchers alike in the design and analysis of underground mine stabilities. Recently MSHA (Mine Safety and Health Administration) specifically mentions the use of the LaModel program for the analysis of complex of non-typical roof control plans. While the use of National Institute of Occupational Health and Safety (NIOSH) pillar analysis programs such as ARMPS (Analysis of Retreat Mining Pillar Stability), AMSS (Analysis of Multiple Seam Stability), or ALPS (Analysis of Longwall Pillar Stability) are still recommended, roof control plans and revisions of complex and/or non-typical underground mining situations are to be supplemented with a LaModel analysis. These complex scenarios are defined as either room-and-pillar retreat mining greater than 1000 feet, bump or bounce prone mines or coal seams, or other criteria considered unusual by the District Manager (Stricklin, 2013). While initial developed as an academic tool, the LaModel program has grown immensely adapting to the ground control concerns and problems within the mining industry. Although being the utilized as the primary design program in over 50 research papers published at the International Conference on Ground Control in Mining (ICGCM) and current regulatory reliance on the LaModel have made it a popular design tool, there is not a comprehensive help file for users to access. With a rising number of users and more widespread use of the program, there is now a large demand for better education and training in the practical application and detailed analysis using LaModel.

The LaModel program utilizes a displacement-discontinuity variation of the boundary-element method for the calculation of stresses and seam displacements in thin bedded deposits such as coal, salt, potash, limestone, or other tabular seams or veins (Heasley and Salamon, 1996). By simplifying the overburden as a series of homogenous laminations within the strata, and by limiting the analysis to the seam itself, the displacement-discontinuity method provides a significant reduction in computation time while providing practical/targeted result over very large areas-of-interest (Heasley and Agioutantis, 2001). The purpose of the LaModel system of programs is to provide mining and geotechnical engineers with a software tool for investigating and optimizing pillar design and mine layout with respect to the overall safety and stabilities of underground works.

1.1 Statement of Problem

Over the past 20 years, mining engineers and researchers have used the LaModel program for improving the design and safety of single and multiple seam mining operations. This boundary-element program calculates the displacements and stresses in thin bedded deposits by assuming a homogeneous laminated overburden. Initially developed for academia and research purposes, LaModel could only analyze small (250 x 250) manually gridded areas providing users with text outputs for seam convergence as well as the element, overburden, multiple-seam, and surface-effect stresses. With the adoption of a graphical post-processor and input parameter forms, LaModel was released to the general public in 1999. While the model is simplistic in nature, LaModel showed early success in its ability to accurately represent the behaviors and characteristics of both in-seam and overburden materials. Soon after, with the development of coal and gob wizards to aid in user generation of material properties and updates to the user interface, LaModel quickly became popular within the industry as an accurate and efficient underground design tool.

Through the efforts of academic researchers and mining engineers, the use and capabilities of the LaModel program have grown immensely while adapting to ground control concerns and problems within the mining industry. The current version of LaModel (LaModel 3.1) allows users to analyze large (2000 x 2000) automatically gridded areas for seam convergences, stress distributions, subsidence, pillar safety factors, and bump or bounce prone regions. While these program updates have greatly increased its utilization by mine operators, so too has regulatory reliance on LaModel. Many of these new LaModel functions were published and employed by MSHA for the back analysis of the Crandall Canyon Mine collapse in 2007. Presently, MSHA specifically calls for the use of LaModel in the evaluation of support and pillar stabilities for non-typical mine layouts including but not limited to mining operations with depths greater than 1000 feet and/or in bump or bounce prone seams. Although multiple publications, research projects, and regulatory reliance on LaModel have made the program a popular design tool, there is not a comprehensive help file for users to access when questions about the program arise. With a rising number of users and more widespread use of the program, there now is a large demand for better education and training in the practical application and detailed analysis using LaModel. In order to inform and train industry professionals, as well as engineering students, an electronic user's manual and comprehensive online training are being developed in this thesis.

The development of an online user's manual and training modules provides users of all educational backgrounds with free mobile access to the details and practical applications of LaModel. Using the electronic manual, users are be able to quickly access information on the installation, use, and troubleshooting procedures of the LaModel program through the incorporations of detailed documentation, software simulations, presentations, and related academic articles. Further information and instruction is obtained by completing the provided self-paced online training modules composed of voiced-over and captioned slide presentations, hands-on software demonstrations, academic articles, as well as related explanations from the manual text. It is the intention of this project to better educate the public on both the capabilities and limitations of the LaModel program through the educational design and online distribution of the LaModel user's manual and training modules.

1.2 Objective

The purpose of this work is to better inform and train academic, industry, and regulatory users on the practical application and technical background of LaModel. Such efforts will improve underground pillar and entry stabilities as well as increasing miner safety and production.

1.3 Statement of Work

A comprehensive electronic user's manual and training modules has been developed to provide a singular source for LaModel reference and training materials. The user's manual allows one to quickly access information on the installation, operation, and troubleshooting procedures of the LaModel program through the incorporation of detailed documentation, software simulations, presentations, and related academic articles. While the manual provides technical details on all of the intricacies of the program, further information and instruction on LaModel can be obtained by completing the provided self-paced online training modules. Comprised of three different educational tracks pedagogically designed to achieve high levels of student learning, educational instruction are given in the form of voiced-over and captioned slide presentations, hands-on software demonstrations, academic articles, as well as related explanations from the manual text. Using the Adobe Technical Documentation Suite, the manual and all training modules have been organized and presented to LaModel users through the creation of an Open Online Learning environment. It is the purpose of this work to better educate the public on both the capabilities and limitations of the LaModel program through the educational design and open online distribution of the LaModel electronic user's manual and training modules.

1.3.1 Manual Text

The electronic user's manual has been designed to assist users of all educational and industry backgrounds on the installation, operation, and troubleshooting procedures for the LaModel program. Using a Table of Contents style navigation bar, users are able to quickly access detailed information on the program in the form of technical documentation, voiced-over and captioned software simulations, presentations, and peer-reviewed articles. By engaging in a series of text documents and video simulations, users are introduced to each aspect of the LamPre, LaModel, and LamPlt programs as well as the Stability Mapping application. While the manual text is intended to provide short program descriptions, the available software simulations and presentations provide users with a more hands on approach while academic articles provide users with a secondary source on the operation and solution options available in LaModel. The development of a comprehensive electronic user's manual provides both the new and experienced users with a basic support system for the LaModel program.

1.3.2 Open Online Learning

Currently, both private and public educational institutions have become more accepting of the e-learning environment as a means of educating students, foreign based nationals, and working professionals. While the Information Age has brought technological and cultural changes in the form of mobile communications, a new educational revolution steps away from the traditional classroom setting and adopts the online learning environment. According to the New York Times, 2012 was deemed the, "Year of the MOOC" or Massive Open Online Course with the launch of online educational platforms such as edX developed by Massachusetts Institute of Technology (MIT) and Harvard University, Coursera developed by professors from Stanford University, and Udactiy developed by Stanford University Sebastian Thrun and University of Virginia professor David Evans (Pappano, 2012). Due its growing global popularity, in Oxford dictionaries defines MOOC as, "a course of study made available over the internet without charge to a very large number of people" (Oxford, 2013). With current enrollment estimated at 10 million users and courses available from over 200 universities (Shah,

2013) , the current online learning practices have proven themselves as adequate mediums for the distribution of information and training available to all users with internet access.

LaModel's self-paced online training modules have been divided amongst three online learning tracks or ability groups; novice, intermediate, and advanced. Each module has been designed to increase and maintain user comprehension of LaModel topics through the incorporation of traditional educational pedagogies modified for deployment in the online learning environment. In completing each educational track, users will have mastered a series of concepts and application skills with respect to their current level of experience in the LaModel program.

1.3.2.1 Novice Learning Track

The Novice educational track provides beginning users with training modules for the initial knowledge and skills necessary to adequately prepare, run, and analyze basic single and multiple seam mining scenarios. The novice user is introduced to the LaModel program and Stability Mapping application through a series of discussions and hands-on activities highlighting their basic capabilities and limitations. Users are first introduced to LaModel through an introductory slide presentation followed by building single and multiple seam models in the Tutorial 1 and Huff Creek hands-on learning activities, respectively. User knowledge is evaluated through the implementation and pedagogical design of educational assessments. In achieving the educational objectives of a given assessment, users will have obtained access to more complex training modules, continuing user progress in the completion of the novice educational track.

1.3.2.2 Intermediate Learning Track

Although structurally analogous to the novice educational track, the intermediate track has been designed to provide more experienced users with the knowledge and skills necessary to prepare, calibrate, run, and analyze the more complicated underground mining scenarios. The intermediate user is introduced to the behaviors and characteristics of fundamental equation for the laminated overburden model through the discussions and hands-on learning activities of the Gory Details training module series. User knowledge and operation of the LaModel program is further enhanced in the Calibration module series where users obtain the skill necessary to appropriately modify input parameters to accurately reflect underground behaviors and conditions. The Solution Options training modules educate users on the forms of analysis provided by LaModel such as seam convergence, vertical stress, pillar stress safety factors, etc. In the final series of training modules, users are further educated in the practical operation of the Stability Mapping application and LamPlt program. User knowledge is evaluated through the implementation and pedagogical design of educational assessments. In achieving the educational objectives of a given assessment, users will have obtained access to more complex training modules, continuing user progress in the completion of the intermediate educational track.

1.3.2.3 Advanced Learning Track

The advanced educational track has been designed to provide the experienced user with a more detailed understanding of the behaviors and characteristics of the LaModel program. As an expansion of the intermediate track, this series of training modules begins by further investigating the behaviors and characteristics of the fundamental equation for the laminated overburden model in Gory Details II. The Solution Options II series of training modules, similar to its predecessor, educates the user on the more advanced forms of analysis provided in LaModel. As the user comprehension and application of the LaModel program becomes more advanced, the user continues their education in the more intricate features of LaModel. In the final series of training modules, user knowledge in the characteristics and behaviors of the laminated model is further assessed in the programming of a simplified LaModel application in Microsoft Excel. User knowledge will be evaluated through the implementation and pedagogical design of educational assessments. In achieving the educational objectives of a given assessment, users will have obtained access to more complex training modules, continuing user progress in the completion of the final educational track.

1.3.2.4 Professional Development Hours

Upon completion of a given educational track, users will be presented with the option of receiving Professional Development Hours (PDHs) equivalent to an estimated time of completion. If PDHs are requested, then a Certificate of Completion will be generated documenting the user's name, date of completion, the educational track completed, and number of Professional Development Hours earned.

1.3.3 Third party Learning Management System

The work composed and discussed in this thesis has been developed for assembly in Coursesites powered by Blackboard, a third party Learning Management System (LMS). While the Coursesites provides no aid in the development and design of course materials, it does provide an up-to-date and user friendly online infrastructure for the delivery and management of instructional content, course administration, event management (i.e., scheduling, tracking), and certification management as well as a series of anti-cheating measures. Due to the availability and functionality of this LMS, the development of a unique online management infrastructure was determined to be beyond the scope of work for this project.

2.0 Literature Review

For the past 20 years, as operations continue to mine at greater depths and in more complex geologic conditions, LaModel has been utilized by both academic and industry engineers as a reliable design tool for the analysis of convergence and stress with respect to the laminated overburden model. Currently the LaModel program has been utilized in over 50 academic papers published at the International Conference on Ground Control in Mining (ICGCM) and is required for stability analysis by MSHA for all "non-typical" underground mine plans. However, as reliance on the program has greatly increased, there is a deficiency of up-to-date, accessible information on LaModel development, operation, and analysis procedures.

In an attempt to educate and training the mining community, many previous novice users have been introduced to the LaModel program through a series of academic publications, on-site training workshops, and on-line tutorials. Still, this introductory knowledge of the program does not create a proficient or competent user. It is the purpose of this research to develop a comprehensive online user's manual and training modules through the incorporation of an open online learning environment implementing historically proven educational pedagogical practices for the enhancement of student learning and comprehension. This online reference source will provide all users with increased accessibility to the program as well as educational materials on the development and application of LaModel.

2.1 LaModel

The LaModel program, originally developed by Dr. Keith Heasley in 1993, implements a displacement-discontinuity variation of the boundary-element method for the determination of convergence and stress distributions on thin seams or vein deposits (Heasley, 1998). Through the application of a homogeneous laminated overburden, the program more realistically represents the natural flexibilities of the stratified geologic overburden and multiple seam mining interactions (Heasley, 2008). In calculating the in-seam convergence with respect to the programs fundamental differential equations, LaModel can currently produce results for stress concentrations, multiple seam interactions, pillar stabilities, and subsidence. The number of solutions options available allows for an increase in practical design application and analysis with respect to current underground mining practices and regulations.

Since launching the program in 1994, LaModel has been continually revised and updated with regards to modernized programming languages and industry/regulatory needs/requests such as the previously mentioned deep cover calibration, increasing number of seams available, fault plane, etc. Originally purposed for academic research, the LaModel program could only define 26 in-seam materials for the calculation of seam convergence and stress within a given 250 x 250 element grid. With the development of a graphical post-processor and input parameter forms, LaModel was first released to the public in 1999 (Heasley, 2008). Currently, LaModel 3.1 allows users to define up to 52 in-seam materials for the calculation of seam convergences, stress distributions, subsidence, pillar safety factors, and bounce or bump prone areas within large 2000 x 2000 automatically gridded areas. In program guides or, "Wizards," help users define and calibrate input parameters with respect to the characteristics and behaviors of the overburden and seam (Heasley, 2011). While software updates have expanded the use of the program, the inherent flexibilities and ease of parameter modifications have made LaModel a well accepted industry standard in the stability analysis of underground mine workings.

In 2007 the Mine Safety and Health Administration (MSHA) heavily relied on the LaModel program for the back analysis of the Crandall Canyon mine collapse (Heasley, 2008). In 2009, MSHA released Program Information Bulletin (PIB) 09-03 (2009) posted general guidelines for the use of numerical modeling in proposed ground control plans. As coal production continued, mining operations found themselves in deeper reserves and more complex multiple seam mining geometries. In response the incidents within the industry, MSHA released PIB 12-09 (2012) a Research Report on Coal Pillar Recovery under Deep Cover in which Congress directed the National Institute of Operational Health and Safety (NIOSH) to, "conduct, in collaboration with the University of Utah and West Virginia University, a study of the recovery of coal pillars through retreat room-and-pillar mining practices in underground coal mines at depths greater than 1,500 ft," (Public Law 110-161). The incident at Crandall Canyon lead to the development of the Deep Cover Calibration method for LaModel. In the past five years alone, the LaModel program has been featured in more than fifteen academic papers and current MSHA roof control plan and review procedures specifically call for the use of the LaModel program in the analysis of pillar stabilities for all mining operations at overburden depths greater than 1,000 feet, beyond the scope of NIOSH programs, in historically bounce or bump prone seams, or other criteria the District Manager deems complex or non-typical (Stricklin, 2013). With increased support of

LaModel from the regulatory agencies, and therefore industry, it has become crucial to increase public accessibility to the program, practical training, and reference materials.

As mining continues to operate at deeper depths and in more complex multiple seam mining geometries there has been an increase in numerical modeling of underground mine works for stability analysis. The LaModel program has had a long history of successful application for non-typical or complex mining scenarios here in the United States and around the world. However, only recently has program seen an influx in users with respect to current mining practices and regulatory requirements. While LaModel provides users with defaulted input parameters to achieve reasonable results for mining conditions, designing specific mine plans or layouts requires the calibration of these parameters to reflect the unique conditions of a given mine site. Currently, users are introduced to the LaModel program through either short online tutorials or 8-16 hour on site workshops. While these methods have allowed for the distribution of the software within the mining industry, user knowledge and program competency is poor. Common LaModel problems typically involve basic operational questions from beginning users and poorly defined model parameters from more experienced users often caused by misconceptions on the implication of their modeling choices. Therefore, in order to increase the knowledge and competency levels of LaModel, a user's manual and training modules will be available online as a reference source to all users.

2.1.1 Current LaModel Information & Training

Basic instruction manuals for the LamPre 2.1 program and on-site LaModel Workshops have been somewhat available to inform and train the general public on the application and limitations of the LaModel program. However, the currently available instructional material is gravely out of date with the most recent tutorial developed and uploaded in 2009 implementing an obsolete version of LaModel, LaModel 2.1. While these early tutorials helped users get started using LaModel, they do not contain explanations on any of the material wizards or the more advanced solution options now available to users. To combat the lack of a comprehensive help file or the availability of up-to-date training materials, one to two day on-site LaModel Workshops are provided as a, "crash course," on the application, calibration, and analysis of the laminated overburden model. After 8 years of providing the workshop service, with the majority of classrooms being at or overcapacity (see Table 2.1), there is still a general need for a singular

LaModel reference source and increased accessibility to the training material. By increasing accessibility to comprehensive and up-to-date training materials:

1) new users will be provided with a more complete background of the program as well as a basic understanding of LaModel's operational procedures,
2) support for intermediate users in using new program features and understanding the underlying mechanics of the program,
3) and develop expert users with detailed knowledge on program mechanics, parameters, and features.

Table 2.1: Summary of LaModel Workshop History

Date	Company	Location	Length (Hrs)	Attendees
7/15/2015	Alliance Coal	Madisonville, KY	8	23
8/15/2015	MEPCO	Morgantown, WV	8	7
5/22-23/2014	Grand Cache Coal	Calgary, AB	12	12
8/29-30/2013	Patriot Coal	Quincy, WV	16	17
3/24/2012	UK, SIU, WVU, MSHA, PADEP, Alpha, & Patriot	Morgantown, WV	8	27
7/21-22/2010	Patriot Coal	Quincy, WV	12	11
1/21-22/2009	MSHA, Arch, Bowie, SUFCO, etc	Denver, CO	8	20
1/8/2008	Many	Grand Junction, CO	4	~ 15 - 20
12/3/2007	MSHA	Tridelphia, WV	8	20
11/29/2007	MSHA	Beckley, WV	8	19
11/26/2007	MSHA	Denver, CO	8	17
10/17/2007	Many	Pikeville, KY	4	~ 15 - 20
10/16/2007	Many	Norton, VA	4	~ 15 - 20
9/20/2007	Many	Twin Falls, WV	4	~ 15 - 20
9/19/2007	Many	Charleston, WV	4	~ 15 - 20
7/30/2007	Many	Morgantown, WV	4	~ 20 - 25

The lack of a singular source of information for the LaModel program creates initial frustrations for new users learning the basics as well as those more advanced users using new program analysis features. Due to this shortage of up-to-date training information, it is presumed that many LaModel users (novice and experienced) abandon the program out of frustration, or turn to more complex, but not necessarily more appropriate commercial programs with friendlier in-program user support and online training modules or video tutorials. Therefore, a comprehensive Online LaModel User's Manual compiled from an updated user's manual and a three track (novice, intermediate, advanced) training course will be developed for the enhancement of public knowledge and understanding of LaModel program and its application to underground stability design. The development of an online user's manual and training modules is intended to replace the majority of on-site workshops and current online tutorials by providing all interested parties with direct access to current and relevant information on the operation and features of the LaModel program.

2.2 Open Online Learning

Over the past decade the global rise of internet availability, increase of computational capacities, and a reduction in cost has amplified claims that new streaming and mobile technologies will provide accessible, quality education to the public (Alexander & Boud, 2001). Currently, both public and private educational institutions have become more accepting of the online environment as a means of educating a variety of students including, but not limited to, on-campus undergraduate and graduate students, foreign based nationals, and working professionals (Marginson & van der Wende, 2007). With current online enrollment estimated at about 10 million users and courses available from over 200 universities around the world, students are beginning to gravitate away from the traditional classroom in adoption of the MOOC or Massive Open Online Course (Shah, 2013). The largest and most attended online educational platforms are edX, a collaborative project between Massachusetts Institute of Technology (MIT) and Harvard University, Coursera, developed by Stanford University professors Andrew Ng and Daphne, and Udacity developed by Stanford University professor Sebastian Thrun and University of Virginia professor David Evans (Pappano, 2012). The popularity of these online learning environments deemed The New York Times to declare 2012 as the, "Year of the MOOC, " and in 2013 the Oxford University Publishers updated their dictionary defining MOOC as, "a course of study made available over the internet without charge to a very large number of people," (Oxford, 2013).

While, "the benefits of eLearning are highly prophesized," many online educational platforms are falling short due to their limitations of student involvement (O'Neil, Singh, & Donoghue, 2004).The constraints on participation are directly related to the fact that many online classroom environments are, "little more than lectures that are delivered online in the form of text, audio, and/or video," (Alexander & Boud, 2001) with pedagogical practices either flawed or missing entirely. Through the analysis of the technology and learning relationship, researchers are finding that students, "listening or reading, by themselves, cannot challenge the learner's egocentric thinking sufficiently to generate new learning," (Ertmer, Sadaf, & Ertmer, 2011).

In an attempt to increase and stimulate student learning, online course designers have been implementing a multitude of activities and secondary methods of participation to increase student involvement in the digital classroom (Stephenson, 2001). Unfortunately there is little research on the effectiveness of these online applications and current research available is often a measurement of a student's ability to use the application effectively (Coomey & Stephenson, 2001) and not a measure of intellectual growth. In developing an online educational environment, it is important that the pedagogical design is not driven by the technology itself, "rather it depends on developing novel forms of organizational processes and structure while carefully maintaining and enhancing the pedagogical principals," (Mayes, 2001) that align themselves with the fundamentals of visual, auditory, and kinesthetic styles of learning.

The value behind an online classroom should be credited to pedagogical improvements rather than just the use of the technology implemented in its design (Jackson & Anagnostopoulou, 2001). In our new digital age, designers often trade productive programs that focus on fundamental learning styles and proven pedagogical practices for ornate, eye-catching design. This often creates learning environments that are busy and distracting, thereby degrading the quality of information retained by the student. To be effective, the online user manual and training workshop should be perceived as a useful reference aid to the LaModel program. Through the execution of pedagogical practices, which emphasize the fundamental learning styles, classroom administrators can monitor and maintain the quality of delivery, information, and student learning within the online learning environment.

2.2.1 Kolb's Experiential Learning Model

Building on the earlier works of John Dewey (1938) and Kurt Lewin (1947), American educational theorist David Kolb believes that, "learning is the process whereby knowledge is created through the transformation of experience," (Kolb, 1984). Through reflections on their educational experiences, one can gain a better understanding and retention of the presented material. First proposed by Kolb in 1984, the Experiential Learning Model (ELM) provides classroom administrators with an outline for designing active, collaborative, and interactive learning experiences that support that student's educational development. The educational theory is presented as a cyclical model of learning consisting of four distinct learning stages; Concrete Experience, Reflective Observation, Abstract Conceptualization, and Active Experimentation as shown in Figure 2.1. Kolb also identified four learning styles which correspond to his four learning stages, highlighting the conditions under which students learn better. These student learning styles are:

1. Assimilators (those who learn better when presented with sound and logical theories),
2. Convergers (those who learn better when provided practical application),
3. Accommodators (those who learn better provided hands-on experiences), and
4. Divergers (those who learn better when observing and collecting a wide range of information) (Kolb and Kolb, 2012).

While students may enter the cycle at any stage, to optimally learn the new task/information one must follow the sequence, participating in each stage, such that the student can observe, think, plan, and apply all educational themes.

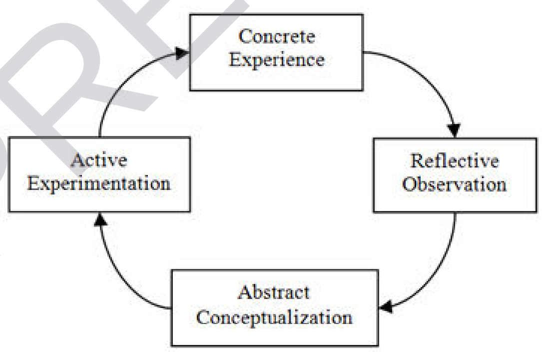

Figure 2.1: Theoretical model of Kolb's experiential learning (Kolb, 1984)

Table 2.2: Kolb's four stages of learning categorized by dimension

Transformation	Concrete Experience	*A new experience is encountered or a reinterpretation of an existing experience.*
	Abstract Conceptulization	*Reflection gives rise to a new idea or a modification of an exisiting abstract concept.*
Grasping	Active Experimentation	*Learners apply thier knowledge to the world around them to see what results.*
	Reflective Observation	*Learners observe in systematic manner and reflect upon what they have observed.*

Kolb continues by simplifying a student's educational development into two categories (see Table 2.2) or, "dimensions." The first dimension, "transformation," recounts the student's ability to acquire information during the learning process. With respect to ELM, a student obtains information by either envisioning a theory or model of what is observed (Abstract Conceptualization) or actively participates in activity familiarizing themselves with a topic (Concrete Experience). The second dimension, "grasping," recounts the student's ability to construct their own conclusions from the presented materials. For this dimension Kolb distinguished between Reflective Observation, where the emphasis is on reflecting on specific experiences and understanding their meaning, and Active Experimentation, which stresses the practical application of the student's knowledge and understanding.

The use of Kolb's Experiential Learning Model (ELM) has been a suitable for classroom design for not only the online learning environment but the traditional classroom setting as well. While learning is focused on and stimulated by the individual student, the experiential learning model is accommodating to a wide range of classroom diversities and can exist without an available teacher or proctor (Itin, 1999). However, the success of ELM is highly dependent on a student's ability to be self-motivated in order to maintain a high level of learning (Kolb, 1984). Through the use of broad learning styles that embody nearly every learner, the learning cycle presented by Kolb allows students to experience, observe, reflect, and apply all educational themes and objectives. While Kolb's model provides a rigid structure and direction within a learning environment, it does not provide any insights on student intellectual activity or knowledge and therefore needs to be supplemented by further pedagogical practices for the identification of student cognitive learning abilities.

2.2.2 Bloom's Taxonomy of Educational Objectives

Implemented in classroom design as a classification system for educational objectives, Bloom's Taxonomy allows for the differentiation of student cognitive abilities (i.e. thinking, understanding, and applying) allowing administrators to evaluate and monitor the inconsistencies between what students learned and what they were expected to learn at a given stage. Originally published by Dr. Benjamin Bloom in 1965, *The Taxonomy of Educational Objectives Handbook 1: Cognitive Domain* has remained an effective educational guide for student learning. Educators have used this theory of learning as a means of achieving a higher order of thinking within the classroom. Bloom's initial taxonomy was intended to provide a classification system for educational objectives, "to help teachers, administrators, professional specialists, and research workers...discuss curricular and evaluation problems with greater precision," (Bumen, 2007). Presently, Blooms Taxonomy provides a framework for sustaining high-level thinking processes in the classroom as well as a means of evaluating the level of learning and the quality of the lesson plans. To guarantee the accuracy of Bloom's Taxonomy it is, "important to assess the student across each of the six levels," (Eber & Parker, 2007) being evaluation, synthesis, analysis, application, comprehension, and knowledge. The hierarchy of the taxonomy is displayed in Figure 2.2 below with each learning level further defined in Table 2.3. Through the use of action verbs listed, one can expand each category to help define different types of learning activities that address a specific cognitive level. Student learning begins at the foundation or Knowledge and progresses to the next cognitive level until the student reaches what Bloom considers the apex of higher order thinking, Evaluation. Through the hierarchy structure, students continually build on previously developed skills obtained from lower levels of learning. For example, in using a mathematical equation for pillar design (Evaluation), one needs to understand the definition (Knowledge), calculation (Application), and consider (Synthesis) the limitations of the given equation. By integrating these previously developed skills into higher levels of learning increases repetition and develops a solid understanding of all skills involved.