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The Classical Model for Knowledge Persistence

Dr. Timothy A Wood, The Citadel

Timothy A Wood is an Associate Professor in the Dr. Emmett I. Davis, Jr. '50, Department of Civil, Environmental and Construction Engineering at The Citadel. He acquired a Bachelor's in Engineering Physics Summa Cum Laude with Honors followed by Civil Engineering Master's and Doctoral degrees from Texas Tech University. His technical research focuses on structural evaluation of buried bridges and culverts. He encourages students through an infectious enthusiasm for engineering mechanics and self-directed, lifelong learning. He aims to recover the benefits of the classical model for civil engineering education through an emphasis on reading and other autodidactic practices.

Stephanie Laughton, The Citadel

Stephanie Laughton is an Assistant Professor of Civil and Environmental Engineering at The Citadel, The Military College of South Carolina. She acquired a Bachelor's in Civil & Environmental Engineering with Honors from Duke University followed by Master's and Doctoral degrees in the same field from Carnegie Mellon University. Laughton's research interests include engineering education and pedagogy, sustainability education, and environmental nanotechnology.

Tess Doeffinger, The Citadel

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Abstract

Engineering educators have long been familiar with Bloom's Taxonomy and the educational benefits from scaffolding learning objectives and activities to grow students' confidence with course content. At the same time, increasing numbers of students miss the connections between courses; their previous educational experiences often resulted in siloed information and a sense that one course has no bearing on any other. The proposed application of the Classical Model of education explicitly encourages knowledge persistence by connecting Bloom's concepts of increasing mastery with scaffolded content between courses. For all disciplines, the engineering curriculum frequently reflects the Classical Model stages of Grammar, Dialectic and Rhetoric. Students start with the fundamental building blocks of math and science (Grammar), use those tools to compare systems in engineering mechanics courses (Dialectic), and then finally use that knowledge to develop new systems in design courses (Rhetoric). The use of Classical Model course maps in multiple courses provides context and continuity for engineering students as they move through the curriculum. Particularly in introductory courses, sub-discipline Classical Model course maps for civil engineering demonstrate how the calculus and science courses are the "engineering" courses in the first year; students are encouraged to master mathematics to support future engineering courses. Likewise, students in engineering mechanics courses are encouraged to master current concepts and remember them for use in follow-on design courses. Students need mastery of course content to fulfill engineering's mission of using math and science to support human flourishing, meet societal needs, and contribute to the public good. The proposed Classical Model course maps encourage students to aim for this very goal.

Introduction

Both the practicing engineer and the engineering educator have identified an ever-increasing need for engineering graduates whose education is holistic rather holey, broad rather than narrow, and multidisciplinary rather than exclusively technical. The need is for engineering graduates who are capable, self-directed, and lifelong learners [1]. At the same time, students are emerging from the K-12 education system trained primarily to regurgitate facts from short term memory [2]. Students appear to arrive at college less prepared for knowledge integration, less inclined to pursue holistic education, and less equipped with the tools of learning [3]. Addressing these needs and challenges calls for holistic thinking about engineering education. The solution might very well be teaching students "not what to *do* as engineers, but [rather] what to *be* as engineers… to think in general, global terms" [4]. Whether through experience or education, engineering students must develop engineering judgment, understanding, and intuition [5]. Engineering students need high levels of knowledge retention and integration, a concept that the cram-exam-forget mindset of many high school graduates fail to recognize as values to pursue. Many college students have no expectation that one course's content will inform or apply to another course. Even if a student recognizes that a later course will require skills from a previous one, they often expect to be re-taught the earlier acquired skill when needed in the later course. Rather than providing prior course re-instruction, educators could provide students with direct instruction in the process and art of learning. Their college experience is designed and predicated on the scaffolding of learning, the retention of knowledge, and the transfer of concepts from one class to the next, from one unit to the next, and from one course to the next.

The following literature review explores how engineering educators have sought to increase knowledge retention, systematically structure the introduction of new topics, and expand the engineering curriculum to meet the profession's needs. The Classical Model is proposed as an alternative and synthesizing framework. It provides a rational and time-tested set of tools for learning, ranging in application from simple concepts to whole engineering disciplines. By viewing the engineering curriculum through the lens of the Classical Model, students and teachers alike can see where they are in their learning journey, attend to the Classical Model tools that best fit their current stage, and generate motivation to persist through and master the content of foundational courses prior to design and capstone courses. Finally, anecdotal student responses motivate future work in applying the Classical Model to the engineering curriculum.

Literature Review

The ASEE literature contains several efforts to improve knowledge retention and integration. Many educators might assume that repeat exposure through in-class review throughout a semester might be key to knowledge persistence; yet at least one study showed no positive improvement in knowledge retention [6]. With far greater success, active, student-centered, and conversational learning activities resulted in greater retention and integration [7], [8]. Modern engineering educators have rediscovered John Milton Gregory's (1822-1898) fifth and sixth laws of teaching: teachers must "stimulate the pupil's own mind to action… [and] require the pupil to reproduce in thought the lessons he [or she] is learning – thinking it out in its various phases and applications till he can express it in his [or her] own language" [9]. Furthermore, both knowledge retention and integration improve when students engage and educators evaluate at higher Blooms Taxonomy levels [7], [10], [11]. Good pedagogy matters when providing a holistic education.

A number of different frameworks have been suggested for following Gregory's law four: "The lesson to be mastered must be explicable in the terms of truth already known by the learner – the unknown must be explained by means of the known" [9]. A "three theme" approach provides a framework for developing student understanding: 1) an introduction to basic principles is followed by 2) experience with mathematical solutions before 3) expanded exploration via modern software solutions [5]. Similarly, a knowledge integration model calls for introduction, exploration, and reflection [7]. In one case study, teaching activities were scaffolded to match each of the six Bloom's Taxonomy levels [12]. Homework questions at three Bloom's levels (Understand, Analyze, Evaluate) effectively engaged students in another study [13]. When it comes to content instruction, three stages of teaching/learning appear frequently in the literature.

At the program level, engineering educators have also noted a need for well-structured and holistic education. Several engineering educators have called for engineering to be integrated into liberal arts education calling for a move beyond the "lesser" content of the ancient Trivium: Grammar, Dialectic (or Logic), and Rhetoric [14], [15], [16]. However, these claims seem to mistake the Trivium for content to be mastered. In actuality, the Trivium make up the tools of learning [17]. Grammar equips students with the vocabulary of thought. Dialectic trains students in logical structuring, the comparing and ordering of thought. Rhetoric forms thought for public communication [18]. Engineering is not an additional content area next to the Trivium, rather engineering is a focused application of the Trivium's stages to the description, understanding, and subduing of the physical world for the flourishing of humanity [19].

The Classical Model

The Classical Model of education prescribed by the Trivium provides a clear and historically proven framework for organizing, introducing, and learning engineering topics. It aligns well with the various three stage teaching frameworks seen in the literature, and pairs nicely with Bloom's Taxonomy. The Classical Model's greatest value is providing students and educators alike a clear language, path, and process for learning. By introducing students to the emphasis of Grammar, Dialectic, and Rhetoric, they can begin to identify new information, how new information fits with previously mastered information, and when they might use their new knowledge and skills to conquer future challenges.

In the Grammar stage, students learn, often through repetition, the fundamental building blocks of the topic at hand [20]. This is the stage of introduction, where students learn the contours and scope of the subject [5], [7]. They learn to name the unique features of the topic and master any specialized vocabulary [21]. Students attend to the most important ideas and learn to differentiate between unique concepts. Through frequent, low-risk, and low-level Bloom's assessment (Remember, Understand) [10], students memorize and express definitions [21]. Frequent peer instruction and storytelling supports the conceptual sharing and deeper integration of knowledge [5]. At this stage, teachers must apply Gregory's law three [9] using the languages (words, sketches, and/or math) most appropriate to the content [22]. The Grammar stage provides educators with the opportunity to drive curiosity about the topic [23].

In the Dialectic stage, students explore interactions between the raw facts learned in the Grammar stage. The Dialectic stage invites students to engage with mid-level Bloom's activities (Apply and Analyze) [10]. Students learn to define each idea more clearly. Comparison between ideas leads to the identification of similarities and differences. With clearly defined categories, students look for relationships, the causes and effects, and the whys of various behaviors. At this stage, students also learn to attend to the context, identifying appropriate assumptions, simplifications, and limitations. Through dialogue with the instructor and peers, students share in the testimony of others to improve their understanding [20]. The Dialectic stage encourages students to connect theory to practice [24] developing the understanding to consider the reasonableness of analytical models [25]. This is the stage for building connections between topics, ideas, and applications [23].

In the final stage of Rhetoric, students finally engage in creative design. Through the practices of memory (thinking back to the Grammar stage) and invention (the association of ideas in the Dialectic stage), students arrange ideas, applications, and concepts to generate new solutions and designs. As they solve problems, student gain the skills required to present their work in the conventional styles, delivering excellent engineered designs [20]. The Rhetorical stage provides the training required for the highest-level of Bloom's activity (Evaluate and Create) [10]. The function (logos), value (ethos), and form (pathos) emphasized by classic rhetoric provides a framework for designs that create value [23], [26].

Hopefully, every engineering educator can see the value of intentionally structuring classroom and student activities to lead students consciously through the three stages of the Classical Model. Students who internalize the Classical Model develop the skills and familiarity with the path of learning required to gain new understanding, insight and design skill after college. Yet this model has application beyond the teaching of individual topics and units; the structure of the traditional civil engineering course of study also aligns with the stages of the Classical Model. To identify and embrace this structure is to help students make the most of not just one class, but all the courses in their college experience.

The Classical Model for Civil Engineering Education

Most engineering educators and certainly, anyone who has been through an ABET accreditation process sees the structure of the engineering curriculum clearly building one course upon another. The first calculus course must be mastered for success in the second. Calculus provides the dominate language for the study of physics. Physics introduces statics and dynamics. Statics provides the foundational skills required for the study of dynamics and mechanics of materials. Hydrology relies on fluid mechanics. A deep foundation design course expects students have a reasonable understanding of soil mechanics. Yet, for far too many engineering students, this reality only dawns halfway through their course of study, when they suddenly wish they had paid closer attention in those earlier courses. The proposed framework captured by the Classical Model course maps might motivate knowledge retention and structure knowledge integration for many civil engineering students.

For each subdiscipline in civil engineering, the Classical Model can provide organization to a sequence of courses. The very definition of engineering outlines the Classical Model: engineering is the use of science, mathematics (Grammar), and the engineering design process (Dialectic) to solve technical problems (Rhetoric). When Classical Model course maps introduce subdisciplines in a first-year introduction to engineering course, students begin to realize that their effort in those first few semesters should be to master the Grammar of mathematics and science. If they are excited about buildings or water treatment, they should be mastering the Grammar of calculus, physics, chemistry, and micro-biology now. As students move into their actual engineering courses, the Dialectic stage of the Classical Model helps them see how mastery in each course equips them for mastery in the next course. By the Rhetorical stage, students should be aware and ready to engage their Grammar and Dialectic stage skills to confront challenges and problems with new solutions, ideas, and designs.

Figure 1 shows the Classical Model course map shared with first year students during a class period devoted to introducing structural engineering. Using an active learning project and photo heavy presentation illustrating engaging projects and topics, instructors hope to drive excitement and curiosity about structural engineering. This slide in Figure 1 directs that enthusiasm and motivation into devotion to their first semester math course. The best day to learn the current courses content is today; today's mastery makes tomorrow's courses smoother. If they desire to become or to work with structural engineers, they need the foundational building blocks and language, i.e. the Grammar, of science and mathematics to pursue that goal.

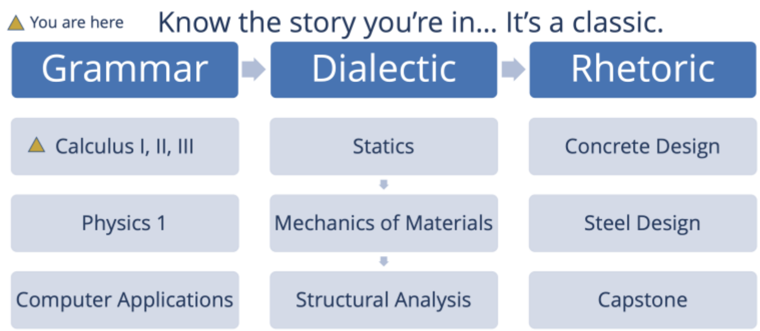

Figure 1. Classical Model course map for Structural Engineering.

Each of the major subdisciplines introduced in the first-year course include a similar Classical Model course map. Table 1 shows the mappings for the courses offered at the authors' university. Arranged in this form, students should embrace the value of calculus and physics in their engineering education. These Classical Model course maps are the key teaching artifact for achieving an important learning objective for the first-year engineering course: describe and illustrate formative content, comparative analysis, and design outcomes for engineering and each of the disciplines and subdisciplines. In Grammar stage courses, students should be eager to master the vocabulary, basic concepts and nuances of the topics covered in these courses to be properly prepared to tackle the more exciting topics of the Dialectic stage.

Table 1. Classical Model course maps for major civil engineering subdisciplines.

	Environmental Engineering	Geotechnical Engineering	Structural Engineering	Transportation Engineering	Water Resources
Grammar	• Calculus • Physics • Biology • Chemistry	• Calculus • Physics	• Calculus • Physics • Computer Programing	• Calculus • Physics • Engineering Drawing	• Calculus • Physics • Engineering Drawing • Computer Programing
Dialectic	• Statics • Fluid Mechanics • Intro to Environmental	• Statics • Mechanics of Materials • Fluid Mechanics • Intro to Environmental • Soil Mechanics	• Statics • Mechanics of Materials • Structural Analysis	• Surveying • Geospatial Representation • Surveying Labs • Asphalt and Concrete Lab	• Surveying • Geospatial Representation • Statics • Fluid Mechanics • Fluid Mechanics Lab
Rhetoric	• Water and Wastewater Systems • Environmental Engineering Lab • Capstone	• Foundation Design • Capstone	• Steel Design • Concrete Design • Capstone	• Transportation • Highway Engineering • Capstone	• Hydrology and Hydraulics • Capstone

In the Dialectic stage, the order of the courses is typically more important than in the Grammar stage. Though the various levels of calculus and physics might be mastered in almost any order, courses like statics and surveying must be mastered to be ready for the follow-on Dialectic courses. In this stage students learn to prioritize and integrate key concepts from Grammar level courses. By the end of the Dialectic stage, engineering students should be competent at describing the world using the vocabulary, diagrams, sketches, and mathematics of engineers.

In the Rhetoric stage, students climb toward that highest level of Blooms achievement, creating and evaluating alternative design solutions, and leveraging all they have mastered in the Grammar and Dialectic stages. The department's award-winning two-semester capstone course sequence gives students a chance to integrate their engineering knowledge and exercise Grammar, Dialectic, and Rhetoric learning skills to master concepts outside their previously explored courses.

Versions of the Classical Model course maps have also been leveraged in other courses in the curriculum. Consider Figure 2; this Classical Model course map illustrates the expectation that students will leverage what they learned or are learning in calculus and physics in statics. A clear expectation removes the surprise when students are asked to remember Newton's Laws of Motion or the basics of drawing a free body diagram. Most class periods begin with this slide and a call and response: "When is the best day to learn statics?!" "Today!" Students are regularly reminded that the first day of mechanics of materials will require calculating reactions and internal forces as learned in statics. Since statics is taught to civil and mechanical engineering students, the Rhetoric section includes both civil and mechanical engineering design courses foreshadowing connections to future courses. The Classical Model course map is a primary means of supporting a critical learning objective: describe the interdependence of statics with other engineering concepts.

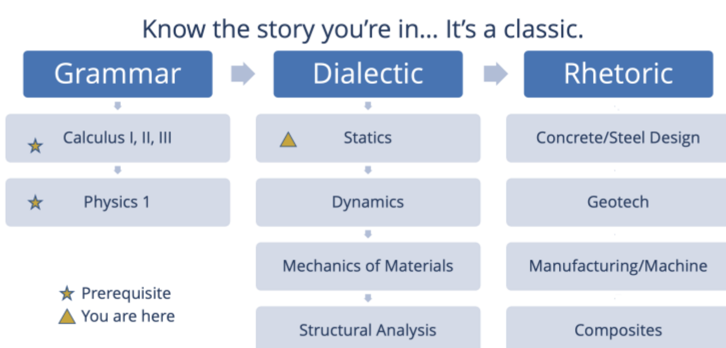

Figure 2. Classical Model course map used in statics.

After early explicit modeling of the Classical Model related to curricular scaffolding, upper-level design courses can assume students will leverage intellectual tools from prior courses and apply them in design rather than demanding in-class instructor-led review. As seen in Figure 3, an excerpt of the course materials from "Hydrology and Hydraulics Design", knowledge transfer from the Fluid Mechanics course is made explicit. Through in-class verbal and online written instructions, students have access to relevant readings and example problems in the textbook for review; however, these topics will not be re-taught during design course lecture sessions.

7. (Review from Fluid Mechanics - Unofficial LO) **Apply** principles from **fluid mechanics** to hydraulic systems for water management.
    7.1. Apply the Continuity Equation in uniform and non-uniform flow scenarios.
    7.2. Apply Manning's Equation to varied open channel scenarios.
    7.3. **Design rigid-lined channels** using best hydraulically efficient sections.
    7.4. Discuss equipment used for discharge measurement.
    7.5. Apply the Energy and the Darcy-Weisbach Equations to calculate an unknown flowrate, head loss, and/or pressure in a closed pipe.

Note: Items in LO7 could be sorted into LO1-6, but they have been grouped together as unofficial LO7 instead to emphasize the how this course builds from concepts of CIVL 320 Fluid Mechanics in order to do hydraulic design.

Figure 3. Design course example of Classical Model expectations used in engineering courses.

Further Work and Student Response

Student response to the Classical Model course maps has been anecdotally positive. Students seem to value the "you are here" reminders and the encouragement to stay engaged in math and science courses. Even in freshmen-level engineering courses like engineering drawing, Classical Model awareness has enhanced intentional engagement with seemingly trivial practice assignments, such as lettering and line drawing. The Classical Model in statics has changed the nature of the surprise on the first day of mechanics of materials. Where students once were dismayed by the rapid-fire review, a growing number of students are pleasantly surprised by their confidence in their ability to recognize the concepts of internal forces and reactions. The student culture is slowly turning toward knowledge integration, and the faculty are noticing more students ready to leverage previous course material as they move into junior and senior courses. Where students have not retained their knowledge or skill, they are beginning to own their temporary failures and seek refreshers on their own rather than complain to faculty or demand instructor-led review.

The authors hope to see more engineering faculty integrate similar forms of the Classical Model course maps throughout their engineering courses at all levels. The hope is to accelerate the cultural transition such that students are eager to master engineering content and graduate equipped with the tools for lifelong learning. Other programs and institutions, at almost no cost, could develop Classical Model course maps from their own curriculum for the benefit of their students. As a way of intentionally addressing student misconceptions about the purpose and structure of the engineering curriculum, the value in a Classical Model course map is self-evident. The success of Classical Model course maps in increasing holistic student development seems best evaluated through informal instructor, advising, and mentoring relationships.

Conclusion

The Classical Model of education with its historic roots in Greco-Roman and Medieval Scholasticism presents a clear set of tools and stages for learning [17]. Classical Model course maps for specific subdisciplines and courses in civil engineering are shifting the student culture and expectations. Students, as early as their first year of college, are engaging with course content with a clearer awareness of its promised usefulness in future classes. The hope of cross-course knowledge retention and integration seems within reach as engineering educators rediscover the pedagogical wisdom that shaped the innovative engineers of previous generations.

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