Enhancing Technical Grading Education: Finding the Right Tools for the Job

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Abstract: Technical grading is a complex task, the mastery of which requires considerable time and repetition to develop the necessary levels of expertise. Mastery of technical grading is not expected in an educational setting; however, competence should be. Through a review of Cognitive Load Theory literature and an analysis of instructor responses to student educational needs when learning technical grading, novel technical grading instructional methodologies were theorized. These methodologies are supported primarily by two-dimensional visualization tools to diagnose levels of student expertise and enhance the development of independent skill and efficiency, which will lead to higher degrees of technical grading competence in landscape architecture students.

Keywords: Technical grading, Cognitive Load Theory, design studio instruction

1 Introduction

Stated simply, grading design involves the alteration of the surface of a site to direct water flow. The reality of technical grading design is much more complex and involves the consideration of above- and below-ground, three-dimensional spatial relationships between people, vehicles, buildings, walls, pavements, utilities, plantings, and more. Considerable time and expertise are required to develop the complex cognition necessary to produce complete and correct technical grading designs. Teaching technical grading skills to diverse groups of novice landscape architecture students is a difficult task for this reason – expertise and time are both in short supply within four- or five-year undergraduate, and especially so within two- or three- year graduate academic programs.

It is well-documented that learning can be enhanced by using both static and dynamic graphics (i. e., visualization tools) in instruction, see SCHNOTZ 2002 for a review. Learning enhancement can occur with the use of visualization tools both in external instruction and internal learning processes. Teaching and especially learning of design skills heavily depends on the use of visualization tools. In external instruction, design concepts (including technical grading) are introduced and discussed, then modelled and practiced within a lecture/studio environment using problems with varying degrees of application to “authentic” or real-world sites and problems. Students are expected to expand their learning of those concepts internally, by exploring design options and relationships with various graphic tools, such as drawing, modelling, rendering and/or animation of views which they employ to visualize and understand the spatial relationships and tactile qualities of their design proposals.

Grading instruction necessarily relies on the use of two-dimensional visualization tools to both explore design relationships and document grading changes. Sections and plans are two common visualization tools relied upon in grading instruction to foster design and documentation of grading plan proposals. Design grading, as a more conceptual, early-process activity, lends itself to design study via three-dimensional modelling. These models may be successfully used to rapidly understand initial conceptual or roughly detailed grading relation-

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ships and surface morphology. Technical grading cannot be easily or quickly explored with precision via complex three-dimensional modelling as the grading must first be completed before it can be modelled. This study hypothesizes that despite the use of complex external visualization tools being less appropriate for use in technical grading design and communication tasks, complex internal visualization operations must be utilized by learners to understand and manipulate the complex relationships among site design components in an efficient and confident manner. How, then, does an instructor best facilitate students' internal visualization skills without relying on the computer to visualize for them? Additionally, how does the student avoid spending time developing complex digital models at the expense of developing the complex cognition required for technical grading competence?

2a Cognitive Load Theory

This study was initiated and informed by a literature review of Cognitive Load Theory (CLT) and through analysis of instructor responses to perceived student needs and direct student questions during a semester-long design studio course. CLT was used as a lens through which to examine potential barriers to student development of the complex cognition required for independent technical grading competence in the studio environment, and to inform instructional changes to help promote higher degrees of learning. CLT assumes that two major goals of instruction are to facilitate the construction of internal schemas (models) and to automate their use to mitigate the significant impacts the limitations of human cognitive architecture have on our ability to cognitively process complex learning (KALYUGA et al. 2003). In this author's opinion, this is the primary goal of instruction in technical grading realms – the development of internal models, as opposed to external models (frequently manifesting as visualizations and/or displays), by which to process the complexity inherent in technical site design thinking quickly and efficiently. The limitations of human cognitive architecture may be described in terms of three types of cognitive loads (for a more complete description, refer to RENKL & ATKINSON 2003):

- **Intrinsic Load** refers to the complexity of the learning material itself. Technical grading instruction may carry a high intrinsic load due to the complexity inherent in the interactivity between many different site design relationships. Intrinsic load is related to a learner's prior knowledge and should be expected to be at its highest levels with novice learners. Intrinsic load may manifest as an information and/or decision-making overload (too many requirements or too many relationships to attend to simultaneously). This load can be decreased with experience as learners develop more meaningful information chunks which can be stored in long-term as opposed to working memory.
- "**Germane Load** refers to demands placed on working memory capacity that are imposed by mental activities that contribute directly to learning" (RENKL & ATKINSON 2003). This is the load learners should focus their cognitive resources on to facilitate learning most successfully.
- "**Extraneous Load** is caused by mental activities during learning that do not contribute directly to learning" (RENKL & ATKINSON 2003). Due to the high intrinsic load inherent in technical grading tasks, it becomes very important for instruction to be designed specifically to reduce extraneous loads. Considerable extraneous load is related to low levels of expertise. Low expertise can contribute to a simple lack of understanding of how to

use available information and tools, and/or inefficient use of the available information and tools.

To limit the impact of intrinsic and extraneous loads, an understanding of the technical grading expertise held by learners is critical to determine what information is relevant and how to present it to maximize the learner's ability to attend to it. Novice learners generally learn better when given higher degrees of instructional guidance as they still need to develop their available schemas. However, more knowledgeable learners (those with more and/or more detailed schemas) may require a different instructional approach that limits redundant information, otherwise they may experience cognitive overload and poor learning, despite their higher level of expertise. This difference is termed the expertise reversal effect (KALYUGA et al 2003). It is theorized that this expertise reversal effect plays a role in the cognitive processes used by students to process technical design instruction activities and in the visualization tools and processes they use to supplement their learning. Therefore, it is important to develop instruction that recognizes and responds to the variable levels of expertise among the students in a course, both related to the processes and visualization tools utilized to complete technical grading design. This study was undertaken to begin to understand the range of expertise variability and to theorize diagnostic tools which can be used in targeting instruction activities maximizing independence and development of expertise in the technical grading design realm.

2b Instructor Response Analysis

The experience of teaching this course over the past three years has been that the most educational impact (i. e. attention to germane load) comes from direct and personalized individual instructor interaction with students during their problem-solving process instead of group classroom interactions. Currently, the instructor must invest considerable time into individual instruction to achieve this impact, so an analysis of instructor responses during these individual interactions was undertaken to balance effort and maximize learning. The analysis seeks to identify patterns among the actions or visualization tools recommended, the frequency of recommendations and how those recommendations were accepted and implemented by the students. Additionally, the analysis sought to determine if there was any discernible impact on the levels of independent thinking and use of visualization tools to enhance internal visualization processes.

The analysis focused on the following interactions due to their potential capacity to directly reduce intrinsic and extraneous loads. Intrinsic loads can be reduced by personalized discussion regarding how to use the information available, and how to produce any lacking but necessary information. Extraneous loads can be reduced by introducing and directly modelling the use of simple, abstract visualization tools to think and produce more complex internal visualizations supporting technical grading design efforts.

Responses were analyzed from interactions over three semesters of a studio course focused on the technical grading design of a complex real-world development site. The fall 2020 studio (enrollment=18) considered a nearly 5-acre office development, fall 2021 studio (enrollment=23) focused on a 7-acre multi-family development and the fall 2022 studio (enrollment=19) designed a 5-acre office development. The course consists of a studio component

Table 1: Interaction Types and Expected Analysis Results

Interaction	Expected Results of Analysis	Type of cognitive load addressed
CAD Lab Workshops Demonstrations	These represent activity interactions, with the labs being primarily visualization tool based. Analysis indicates how students connect the dots between information and design action – how they use available tools to think and communicate.	**Intrinsic Load*** Extraneous Load
Desk comment/ critique	Analysis documents the recommendations and their frequencies in terms of both design process/thinking and use of visualization tools to think and communicate.	**Extraneous Load*** Intrinsic Load
Written comment/ critique	How did the students respond to the recommendations made above? What recommended elements or visualization tools remain unaddressed?	Intrinsic Load Extraneous Load
Instructor notes**	Analysis documents larger scale issues such as course organization, presentation of lecture and lab material, and identifies opportunities for addressing reductions primarily with intrinsic loads.	Intrinsic load

*Bold type indicates the primary load being addressed by the interaction.
**Not an interaction with students but included as a reflective, internal interaction.

with 460 minutes (7.7 hours) of weekly contact time (which includes lecture time) and a separate 110-minute (1.8 hours) per week CAD lab component. All students in the target course were novices with a negligible degree of variation among their prior grading expertise. All students were introduced to grading activities in an earlier course with a focused grading component where they were presented the grading process, techniques for visualizing landform and interpolating elevations, and developed grading skills via a grading design project.

3 Variability of Student Expertise

Results of the study identified potential barriers to learning situated within four pathways:

- **Lived Experience Variability:** This pathway is defined as individual differences in recall/codification (chunking) of actual human experiences, such as walking across surfaces, transitioning grade-change devices, noticing materials/textures/connections/joints, etc. and linking or chunking those experiences together with technical grading skills in meaningful ways.
- **Causal Chain Recognition:** The skill to recognize critical relationships among existing and proposed component parts in the context of a technical grading design.
- **Internal Animation:** The ability to internally animate objects to transform them rotationally and/or positionally within the site, or to animate and visualize water flowing across/through elements of a site.
- **Digital Expertise Variability:** This pathway defines individual differences in both knowledge of digital visualization tools (what they are and what they do) and how to make them work to solve particular problems. This pathway refers both to simple inexperience/lack of knowledge, and self-inflicted or self-limiting inexperience (such as refusal to spend the time needed to fully understand a software program).

Learning activities in the first three of these pathways require the use of relatively simple external visualizations (such as diagrams, plans and sections) to support considerably more complex internal visualization and transformation operations such as flows and inferred motion – both of which represent aspects of mental animation (HEGARTY 1992).

Causal Chain Recognition supports the identification and documentation of critical relationships between site plan elements, and the visualization of responses to transformations of plan elements. CCR is the skill one would use to understand that as one corner of a flat rectangular pavement surface is depressed (lowered in elevation), the rest of the pavement surface will tilt in that direction unless the surface is broken, creased, or otherwise deformed to accommodate multiple slopes. Thus, complex internal animation is required to mentally transform **site objects and/or surfaces** with elevation differences efficiently without relying on an external visualizations to understand those transformations.

Internal Animation is a skill utilized when considering how water moves across and/or through the system. Assuming water droplets remain intact from the moment they strike the surface until they leave the site at the outfall, technical graders should be able to trace a drop of water from the point it contacts the surface all the way to the site drainage outlet using internal animation. This skill requires the **water** to be mentally animated as it travels across surfaces and through conveyances.

It is hypothesized that Causal Chain Recognition, Internal Animation and, to an extent, Digital Expertise Variability can be directly influenced via instruction emphasizing germane loads, though this paper focuses only on addressing improvements to Causal Chain Recognition and Internal Animation. The study was conducted under the assumption that the creation of complex external visualizations, such as detailed 3D models, would contribute to higher extraneous loading in the context of the technical grading course, so instructor responses were constrained to primarily 2D graphics, including static 3D views, but not models. Highly detailed 3D models of proposed grading solutions were not required or recommended by the instructor as a part of this course. However, TIN surfaces created from existing contours were required to be created using Civil 3D, and the use of the "Quick Profile" tool recommended for understanding existing topography and quickly testing proposed solutions and relationships. Additional solutions have been considered to address Lived Experience Variability, but those have yet to be implemented and tested in the course and will be addressed in a future paper.

4 Instructional Methodologies

Four novel technical grading instructional methodologies have been theorized to address learning improvements for each of the pathways mentioned in the previous section. Instructional methodologies were developed to both function as diagnostic tools to identify needed areas of focused instruction, and to facilitate the packaging or "chunking" of information to minimize negative cognitive loads and enhance development of technical grading design skills in novice learners.

Spot Skipping: a method of intentionally widespread, but very limited calculation of spot elevations early in the grading process which directly supports the recognition and calculation of critical grading relationships as a part of the Causal Chain Recognition pathway.

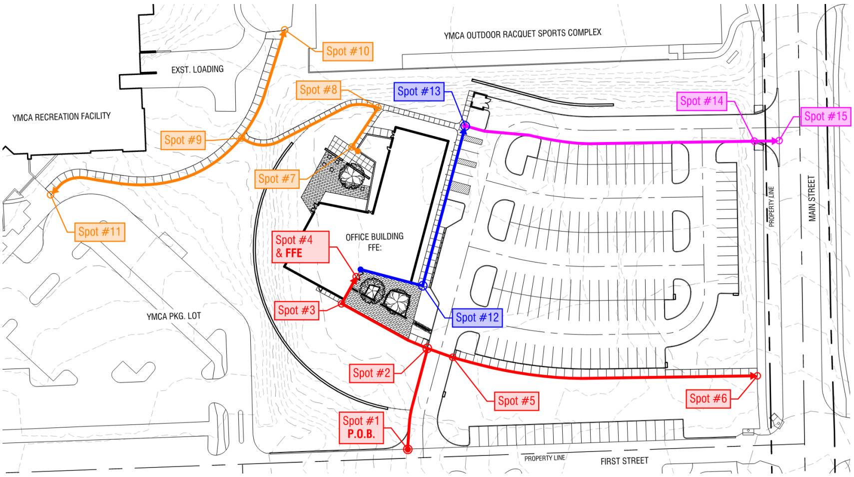

Fig. 1: Spot Skipping applied to course project site. Finished Floor Elevation was set and functionality for accessibility preliminarily determined by calculating only 15 spot elevations. Multiple iterations would be likely to fine tune major relationships.

Flow Branch Analysis: a method targeting spot elevations defining individual branches of the site flow pattern to analyze flows and inform early technical grading design. This method of analysis is primarily concerned with flow lines and may be used independently or concurrently with Spot Skipping and primarily supports Internal Animation as water flows are visualized and defined across a site.

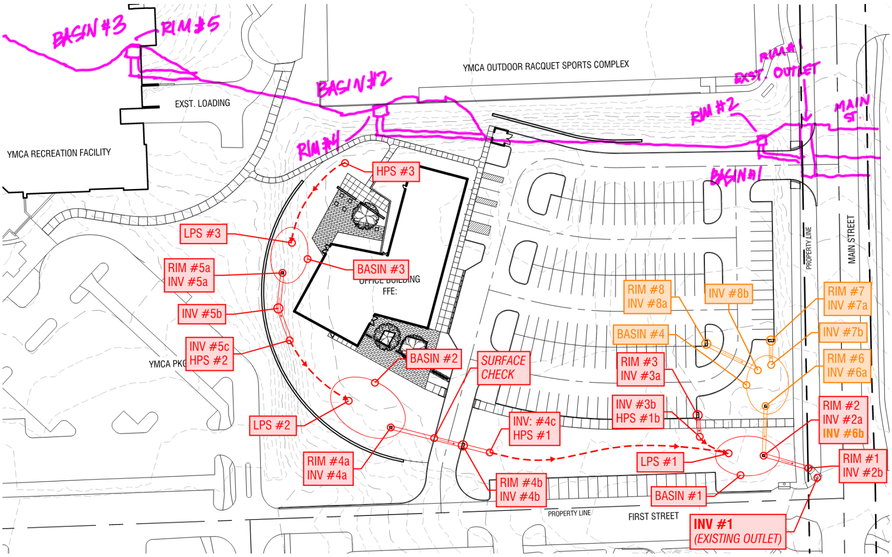

Fig. 2: Flow Branch Analysis for both major flow networks on the project site. Confirmation of elevational relationships would be checked against elevations calculated during Spot Skipping. Note the imprecise and inaccurate section utilized to help visualize grading relationships.

Flow Barrier Analysis: a method of analyzing site plan objects in terms of their impact on water and/or people flows. This method of analysis allows for the chunking of the site into flow barrier types and works to define and describe water flow patterns supporting Internal Animation.

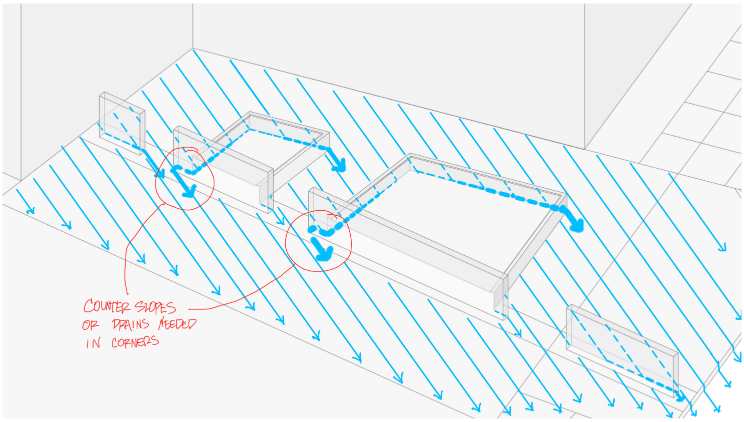

Fig. 3: Flow Barrier Analysis conducted on the building entry plaza using simple (flat) 3D model view created quickly in SketchUp. Analysis can be more efficiently done with a plan diagram once expertise has been established with internal visualization and animation skills.

Transect Grading: a method of spot grading along discreet transects, usually drawn perpendicular to water, pedestrian and/or vehicular flow paths, rather than at locations where spot elevations would be commonly calculated and included on a technical grading plan. Transect

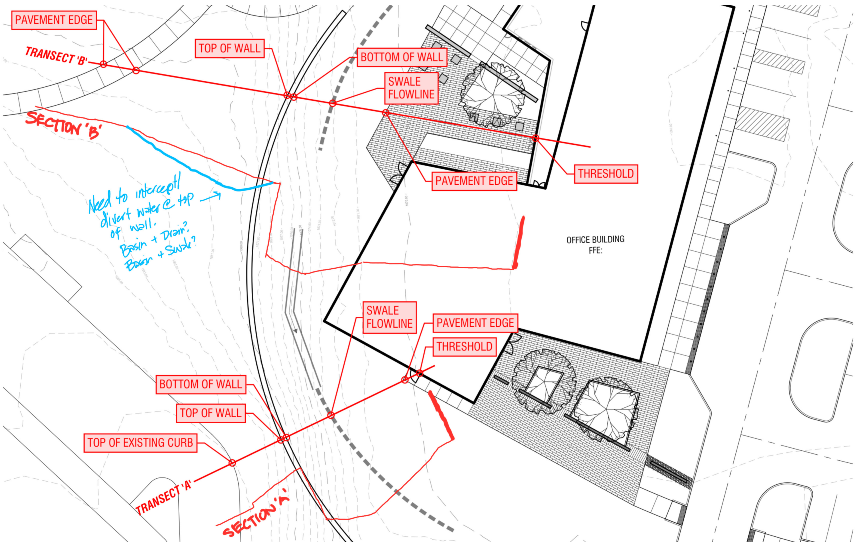

Fig. 4: Transect Grading used to visualize spatial relationships of site elements, internally animate contributing flows to the main flow trunks defined via Flow Branch Analysis, and discover conflicts or missing grading elements.

Grading is another method of chunking the critical relationships between elements of the grading plan into easy-to-understand sections, primarily supporting Causal Chain Recognition. Transect Grading may also be used in conjunction with Spot Skipping and Flow Branch Analysis.

5 Discussion and Conclusions

Evidence from preliminary use of the four instructional methodologies described above in the fall 2022 course seems to support the hypothesis that certain visualization tools may impose high extraneous loads on students. Their level of expertise in both interpreting critical grading design relationships and in the construction of suitably precise models is low enough that they don't yet have the detailed schemas needed to develop efficient, low-extraneous-load processes. 3D model construction was deemphasized in the course and student outcomes seemed to improve. Whether the improvement was related to the lack of effort spent on model-building or simply more time developing grading skills has not yet been studied. However, CLT would support the notion that regardless of the reason, germane loads were prioritized and learning improved.

Table 2: Instructional Methodologies and Supporting Visualization Tools

Instructional Methodology	Visualization Tools
Spot Skipping	Grading Plan Imprecise Sections
Flow Branch Analysis	Imprecise Sections Site Plan with precise flow lines
Flow Barrier Analysis	Plan Diagram Imprecise 3D Views
Transect Grading	Site Plan with precise site object locations Imprecise Sections

Results suggest that, while digital drafting tools and Civil 3D can assist in drafting precision and in the process of working through the four methods, no complex visualization tools are required to achieve a high degree of expertise in technical grading (see Table 2). Even the 3D views may be sufficient if drawn inaccurately by hand or quickly and roughly modelled without any elevational precision in a program such as SketchUp (see Figure 3). Documentation and external communication of the grading solution may be best completed with sophisticated visualization tools, however this communication is secondary to the grading itself. The development of the grading design, to a high degree of detail, should be easily achieved using simple drafting tools and hand graphics if care is taken to do so with the required precision. This hypothesis must still be tested to confirm whether the use of complex external visualization tools would be helpful in developing internal animation skills among novice technical graders.

The production of a construction document quality grading plan has been a requirement for each iteration of this course and, given the complexity of the Civil 3D platform used to document those solutions, it is possible that some of the negative observations within the study may stem from extraneous loads imposed by the required documentation rather than issues regarding grading skills. The opinion of this author is that construction documentation should be an integral part of any technical grading plan. The primary purpose of the technical grading plan is to facilitate site construction and, learning to communicate design intent to the appropriate audience with the appropriate visualization tools should be the goal of any design education. Perhaps there should be a different focus on the documentation aspect of the grading plan, either concurrently or in a different semester. More work needs to be done to determine where any differences might exist between grading design skill and grading documentation skill.

It is important to note that the methodologies examined in this paper were applied to fine grading of a site surface. Detailed considerations of mass grading and site stormwater management, such as balancing cut and fill and sizing stormwater management facilities were not included as a part of the target course. Accordingly, additional research must be done to examine the relationships between successful fine (surface) and mass grading activities while utilizing the methodologies described in this paper.

This study raises the question of which approach is the most appropriate for the most efficient transfer of knowledge and development of technical grading skill, the project-level approach, focusing on direct, real-world application (as presented in this paper), or the vignette approach, focusing on individual skill development and repetition. The course within this study primarily relies upon the former, project-level approach, but does incorporate aspects of the vignette approach within the workshop and demonstration interventions, and the opinion of this author is that a combination is ideal. More work is required to answer the questions of what that combination should look like and how much time and effort should be spent by instructors and students within each. The four methodologies developed through this study should be developed into an online rapid diagnostic tool to identify the levels of technical grading expertise in a student population over time, and to match more detailed instructional methodologies to those students to help them overcome challenges to cognition and development of the expected technical grading competence. This study also suggests that additional exploration is required to more fully understand the relationship between cognitive loading and the use of digital design skills and visualization tools versus analog design skills and visualization tools in an educational environment, especially in the realms of technically complex design tasks.

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