Automated Grading for CAD in Engineering Education

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Automated Grading Platform in Engineering Education

Abstract

This work highlights the development and implementation of an Automated Grading Platform (AGP) for Computer-Aided Design (CAD) in engineering education using *Solidworks*. AGP addresses challenges in teaching engineering graphics, particularly the grading of numerous parts while providing timely feedback. The platform compares submitted parts to a reference design, ensuring accuracy based on instructor-defined thresholds. Submissions that fail to meet these criteria are rejected, allowing students to refine their work and achieve course objectives. AGP offers flexibility by encouraging students to take risks, learn from mistakes, and engage critically with peers and instructors in a supportive environment. Instructors benefit by being relieved of repetitive grading tasks, enabling a stronger focus on design strategies and deeper student support. The system is also suited for remote learning via a secure Virtual Private Network. AGP improves academic integrity by detecting and marking duplicate parts, blocking resubmissions, and allowing instructors to address plagiarism proactively. Implemented over multiple semesters in the "Engineering Design Methods" course for Mechanical Engineering students, AGP has demonstrated improvements in learning outcomes and created a more interactive learning environment. Surveys, performance metrics, and instructor feedback affirm AGP's impact.

1. Introduction

In engineering graphics education, the use of modern Computer Aided Design is prevalent. Not to supersede hand sketching, visualization and documentation [1,2] but to support building advanced engineering graphics skills by offering parametric solid modeling, sometimes known as constraint-based CAD that allows users to capture design intent and to take full advantage of the desktop computer as a design tool [3]. Like *SolidWorks* [4,5], most of the CAD software are constraint-based CAD and learning the skills using one software or the other wouldn't matter since the rules of engineering graphics remain the same. In fact, a student needs to build a visual language of engineering using precise technical drawings to communicate design ideas and specifications [1]. This is done by making 3D parts, fixing mistakes and exploring best practice in designing an object. The emphasis is on both correct part geometry and design intent as it is critical that students move beyond simple procedural knowledge (i.e command knowledge) and develop proficiency in higher level strategic thinking (i.e finding optimum modeling(s)) [6,7,8,9]. Hammad et al [10] proposed an indirect measurement to assess proficiency using two measures: (a) performance speed (time needed to build the part until it's accurate) and (b) feature count (the number of construction steps or features used to build a model). However, the feature count might be subjective as, depending on the part complexity, there might be many optimal ways to design the object.

One of the main challenges a Computer Aided Design (CAD) instructor encounters is the time consumed to grade students' 3D parts, from the fact that the instructor needs to open each digital file, check features, sketches, dimensions…etc and assign different parts. This becomes problematic when evaluating a large number of students' models, thus increasing the time until students receive feedback after they submit their work. The instructor would rather use the time in conveying design knowledge through the creation of various designs, the discussion of optimal strategies, and the application of engineering graphics standards. In fact, teaching CAD presents a unique set of challenges for both the instructor and the students, and shifting the way of teaching CAD courses became a necessity. Practice and collaboration are essential for achieving a high level of competency in engineering graphics, the question remains: How can educators accurately grade and check a large number of parts while providing timely feedback to each student?

In the last two decades, researchers have been exploring ways to build an automated grading system to reduce grading time. Baxter et al [11] introduced a computer program to automate grading 3D parts by using a reference part to be compared to a student's 3D part. This was done based on criteria set up by the instructor. The authors didn't reveal any information about the grading algorithm. Ault and Fraser [12] presented an automated system of 3D models to be compared to the instructor 3D part and the system is based on the number and types of features, existence of dimensions within sketches, and physical properties like volume and shape. In this system, checking for specific dimensions can be problematic because there are often multiple valid ways to dimension an object. Otto et al [13] presented a semi-automatic system focused on both surface and parametric feature-based solid models for a single specific part. The tool supports instructors in providing more objective and frequent formative feedback. Kirstukas [14] developed a computer program that uses the "gold standard" (instructor's reference model) to detect model issues and deduct them from students' scores. The program is executed directly within the CAD application's interface and presents twelve different deduction categories from which the instructor selects the ones to be checked (such as undefined sketches or banned constraints). The program is useful in detecting issues for different models but the authors stated encountering some issues with dissimilar parts that present similar dimensions or student models with significant problems may get lower scores than a blank model if they have sufficient unconstrained sketches, missing dimensions, …etc. Garland and Grigg [15] compared human and software grading in an engineering CAD course using Graderworks [16], a commercial software that Dr. Garland developed in partnership with *Solidworks*. Graderworks can compare geometric properties such as volume, center of mass, and moment of inertia to a reference file. Instructors obtain an excel sheet with related data grading. The instructor can then merge-mail the scores to the students. The Bojcetic et al [16] method allows for more refined grading criteria, grading features, and sketches but it takes some time for the instructor to set up the rules for grading through multiple iterations. The authors stated some issues related to assigning points to the student even if they didn't use any feature in some cases or grades may have been lower even when a minor mistake was made (e.g., student did not define the length of the symmetry line)". DiZinno and Jean-Pierre [18] introduced an automated grading platform (AGP) as a web-based platform (work-in-progress) that instructors monitor without a need to send feedback via email. The most recent work is by Hekman [19] who developed an email-based grading system. The author compared the geometric properties (volume, center of mass location, and mass moment of inertia) of student's file to a reference part. In addition, the system sends an image with highlights of incorrect part shapes within the part and students can compare the image with the STEP file provided by the instructor. The author stated that for some files, the document compare function did not work.

The present work describes the Automated Grading Platform (AGP) implemented in the “Engineering Design Methods” course for Mechanical Engineering undergraduate students. AGP allows students to submit their parts and get a quasi-instantaneous feedback at any time within the time window of the assignment. If the part is rejected, then the platform will provide some feedback so students can correct their mistakes and submit again until the part is accepted.

2. The Course

a) Context

The “Engineering Design Methods” course is required for all Mechanical Engineering majors but is also taken as an elective by some students in other majors. Most students in this course are freshman or sophomore whereas a few juniors can attend the course as well. At the author’s University, *Solidworks* is the Computer Aided Design (CAD) software used in the course, which is offered every semester and enrolls approximately 150 students each year. Students develop skills in hand sketching and visualization, drafting standards and specifications, 3D modeling using CAD, and the generation of 2D engineering drawings. In addition, students learn best practices for designing precise, manufacturable parts. In addition, students are introduced to Finite Element Analysis (FEA) using Solidworks to give them a sense of editing a part to satisfy the needs. Students also learn how to create assemblies; however, the Automated Grading Platform has not yet been used to grade drawing files or assembly files.

Students focus on creating effective designs by minimizing unnecessary features, reducing modeling time, and making sure parts are easily editable. For instance, when designing a part to satisfy specific geometric requirements within an assembly, while also withstanding a defined load, the student will be able to change/edit the part to satisfy those requirements. In this work, AGP is not meant to assess design intent but to assess the final geometry quasi-instantaneously allowing more time for discussion and manual feedback on the modeling process. The authors see perspectives in assessing design strategy by extracting feature data. However, the grading form would need to be customized for each part due to the fact that, for some parts, only one good modeling process is acceptable whereas, for other parts, multiple good modeling processes are possible.

The instructor in this course is supported by two Course Assistants (CAs), Mechanical Engineering graduate students who previously completed the course during their undergraduate program. They provide support during class meetings and office hours, assist with grading students' work such as hand sketching assignments, and provide individualized feedback on digital files for deeper instructional support.

The goal of implementing the Automated Grading Platform (AGP) is to provide instantaneous feedback on student work, therefore freeing instructional time for discussion of best practices and strategies for optimal design. Maintenance and continued development of AGP were carried out by an additional Course Assistant (Computer Science graduate student developer) provided by the Digital Learning Department, under the supervision of the instructor and the Senior Director of Digital Learning and Teaching Innovation during Spring 2025.

b) Assignments

To assess students' 3D modeling skills using *Solidworks*, assignments are structured as a pool of parts from which students may choose. Parts are worth from 1 to 5 points depending on how "easy" or "challenging" they are. Students are required to earn a total number of points for a given assignment. For example; for a 10-point assignment, a student can choose to make 2 "hard" parts each worth 5 points, or instead choose 4 parts each worth from 1 to 3 points. Each assignment is open for a defined submission window during which students may submit and resubmit their parts as many times as needed to achieve an expected design, supporting an iterative design process. The instructor's aim is to encourage students to take risks, learn from mistakes, and engage critically with peers and instructional staff.

c) Total Quality Management

In this course, the concept of grading the 3D models is the pedagogical paradigm of Total Quality Management (TQM - *of continuous improvement*) [20,21]. The instructor defines work on a particular assignment as exemplary if the dimensions of the student's part match those of the reference part to a certain threshold (for instance 94%). A student's work is then *accepted* if it meets a standard of excellence as defined by the course instructor. If there are any flaws, the part is *rejected* and students will receive feedback and have the opportunity to revise the work until the part is accepted. The concept of TQM – *of continuous improvement* combined with the Automated Grading platform for quasi-instantaneous feedback offers students the opportunity to work more on the design until reaching a standard excellence. Thus, building Engineering graphics skills in a supportive learning environment [18].

3. The AGP Application

The Automated Grading Platform application described in this work was developed to support assessment in the undergraduate *Engineering Design Methods* course by integrating assignment management, feedback, and instructional workflows into a single platform structured for design-based courses. The course is project-based and centered on iterative 3D design.

Grading and providing feedback on 3D design assignments presents continuing challenges, particularly at scale. Instructors must review large numbers of submissions and multiple design iterations while balancing feature verification, revision and resubmission practices, grading workload, academic integrity, and course coordination.

AGP was designed to support instructional workflows in the course by centralizing the approach to assignment setup and management, submission, and review. Instructors use the platform to define semester assignments, monitor student progress, and review course assignments over time. Graduate assistants support grading and feedback through structured access to submissions and revision histories, enabling consistent assessment in the course.

a) Functionality

AGP accepts SolidWorks part files (SLDPRT) submitted by students and automatically extracts key information, including mass, volume, surface area, center of mass, and moment of inertia. Additional metadata, such as file creation date and version history, are recorded to support tracking of design progression across submissions.

For each assignment, instructors create a reference SolidWorks part that serves as the benchmark for evaluation. Student submissions are compared against this reference model using the extracted parameters, and submissions that fall within instructor-defined margins of error are accepted. Students may submit repeatedly prior to the deadline and receive immediate feedback indicating which criteria have not been met. This supports iterative refinement of designs while applying the same predefined evaluation criteria to all submissions.

b) Platform Design

AGP is accessed by instructor and students through a web-based interface available on the university network, supporting use across courses and instructional contexts. The platform provides role-based access, with separate interfaces for instructors and students.

Instructors can manage multiple students across sections and courses within a single environment, supporting coordinated assignment management and grading at scale. Students register at the start of the semester using a course-specific access code, after which their accounts are activated by the instructor, allowing instructional staff to control enrollment and maintain alignment with course rosters.

Instructors can create assignments by uploading reference files for the parts students are expected to design. For each part, instructors define evaluation criteria and margins of error for certain properties, such as volume, surface area, and mass, while other criteria, such as moment of inertia and center of mass, are fixed. (Figure 1)

Assignments may contain multiple parts, each scored on a discrete scale determined by complexity, with the instructor specifying the minimum score required for full credit. (Figure 2)

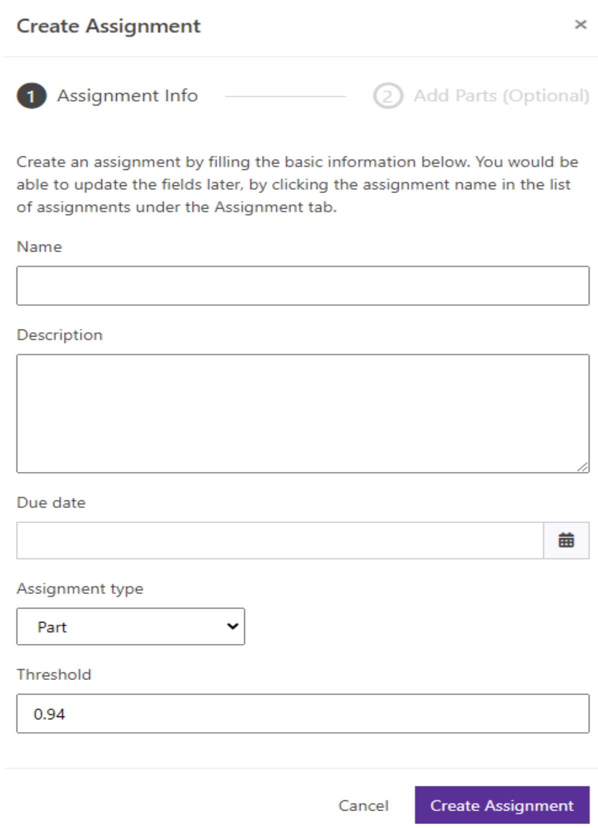
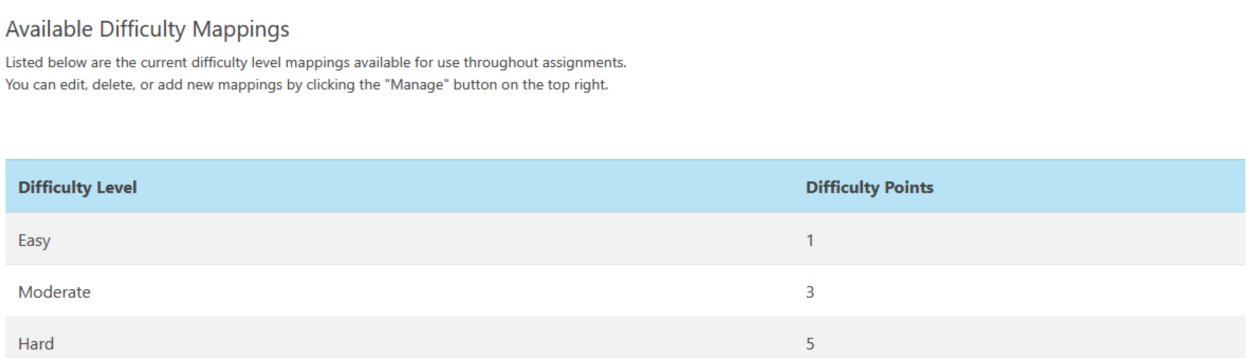


Figure 2: Assignment creation window



Available Difficulty Mappings

Listed below are the current difficulty level mappings available for use throughout assignments.
You can edit, delete, or add new mappings by clicking the "Manage" button on the top right.

Difficulty Level	Difficulty Points
Easy	1
Moderate	3
Hard	5

Figure 1: Difficulty mapping

Student submissions are graded immediately upon submission using the SolidWorks API, which allows to extract important information about each part file generated by the student. Students may submit parts repeatedly before the deadline, receiving automated feedback indicating which criteria were not met. (Figure 3)

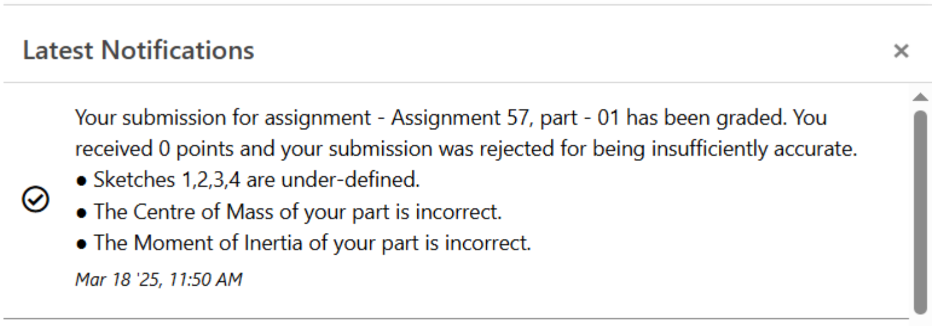


Figure 3: Example of a feedback to a rejected part

This iterative submission process encourages reflection, experimentation, and incremental improvement, with all submissions evaluated fairly using the same predefined criteria. Throughout and after the assignment period, instructors have access to detailed statistics and submission histories, with options to filter by student, assignment, or other criteria. They can download scores, submission data, and the part files themselves, supporting consistent grading, data-driven feedback, and evidence-based evaluation.

c) Plagiarism Check

AGP includes functionality to support academic integrity in design assignments by identifying potentially plagiarized submissions. The platform compares metadata extracted from student submissions against records from prior submissions, including those from previous course offerings, to identify similarities that warrant review. (Figure 4)

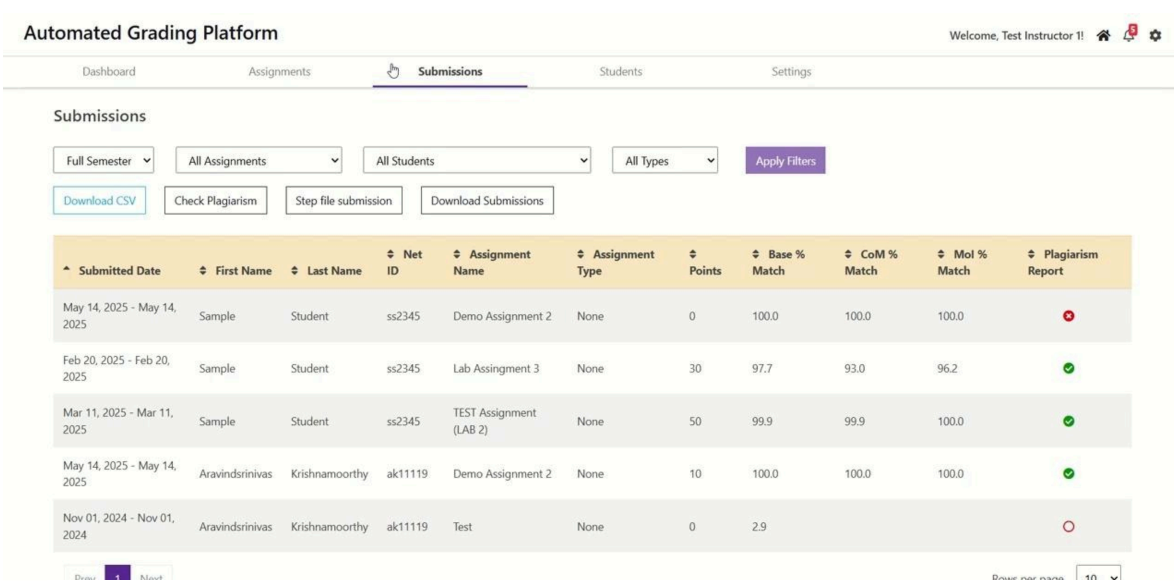


Figure 4: Instructor view of students’ submissions

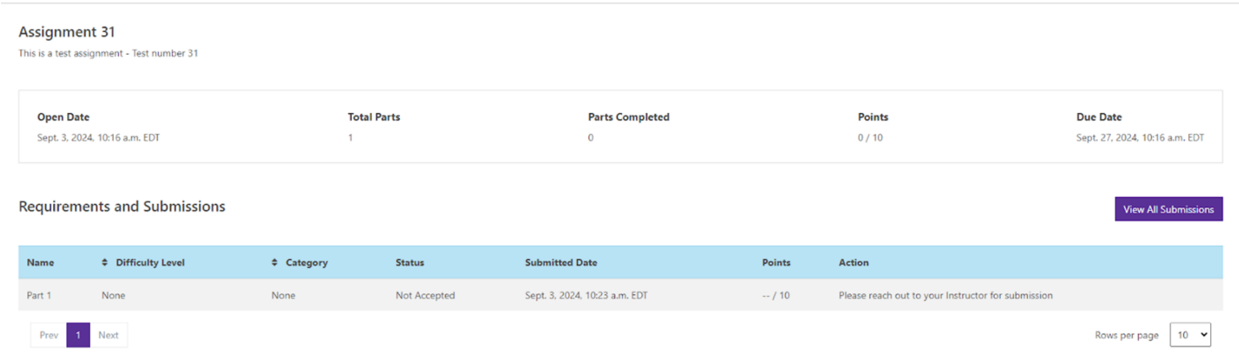


Figure 5: Student's view - plagiarism case

When a submission is flagged, the case is directed to the instructor for evaluation. During this review period, the student's ability to submit additional attempts for the affected part is temporarily restricted. This workflow allows instructors to determine appropriate next steps for the assignment before permitting further submissions. (Figure 5)

Submissions that are reviewed and cleared are visibly marked within the platform, providing transparency in the review process while preserving the integrity of subsequent submissions. (Figure 6)

Symbol	Meaning
✅	All the parts of the student's submissions are successful with no notes
⭕	At least one of the student's submissions had been flagged for plagiarism but they have been allowed to resubmit
✕	At least one part of the student's submissions had been flagged for plagiarism and submission for that part has been restricted

Figure 6: Submission checking using color code

4. Result and Discussion:

Data represented are those of Spring 2025 from assignment 2 (A2) and assignment 3 (A3). For assignments such as hand sketching (assignment 1) and multiple-choice exams, AGP is not used. It was, however, used for grading parts of assembly-based assignments. Overall, AGP was used in approximately 70% of the course's graded assignments.

- Assignment 2 (to earn 10 points) – parts are labeled from *2A* through *2O*: Students make 3D models from reading given 2D drawings. AGP was used for grading.

Students can choose “easy” (worth 1 point), “medium” (worth 3 points), and/or “hard” parts (worth 5 points). A2 was open for 15 days.

- Assignment 3 (to earn 30 points) – parts are labeled from *3A* through *3P*: Students make 3D models from 2D drawing or isometric views. Students can choose “medium” (worth 3 points), and/or “hard” parts (worth 5 points) only. A3 was open for 25 days.

Sample examples of *easy* parts, *medium* parts and *hard* parts are represented in figure 7. The parts are selected to each category by the instructor based on the sketch and feature tools learned in class combined with the instructor’s expectations.

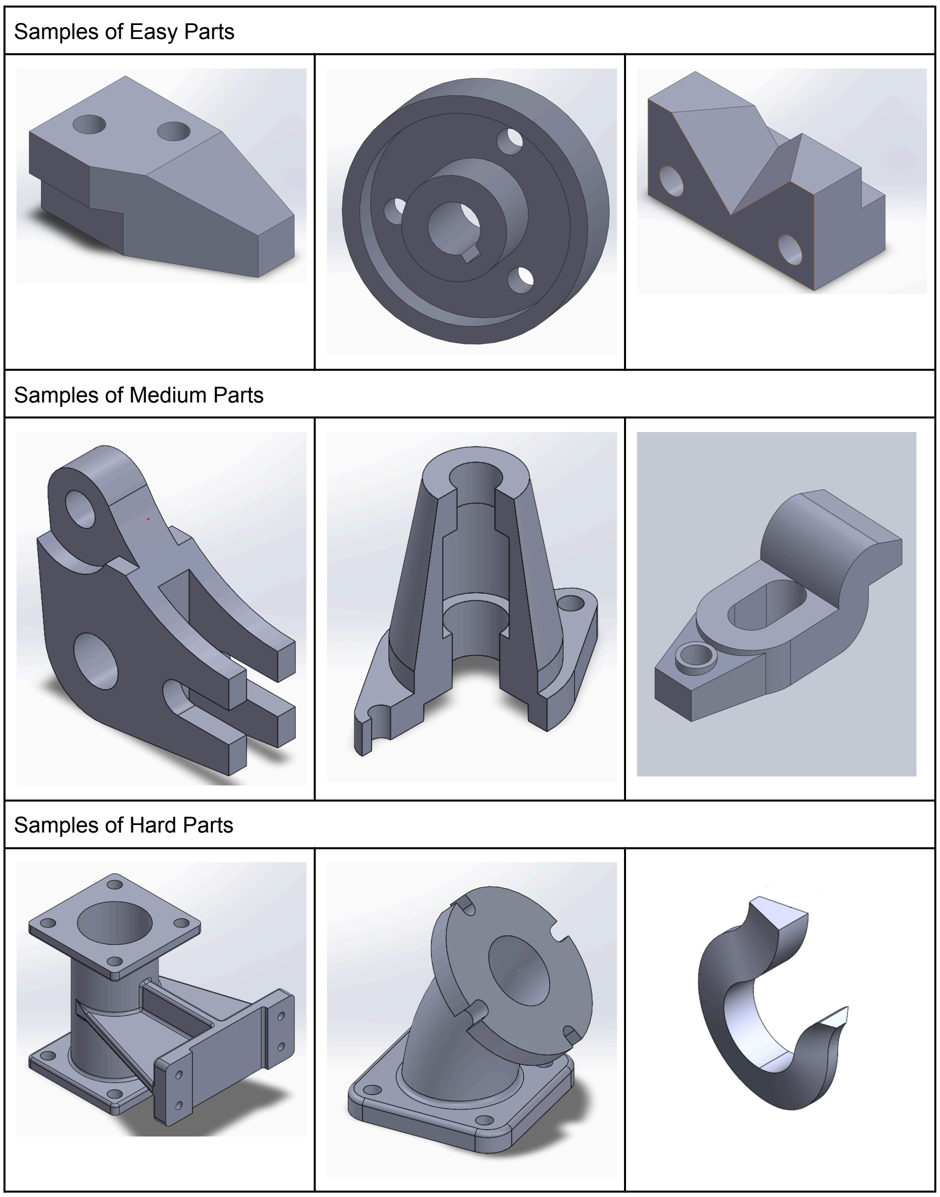


Figure 7: Samples of *easy* parts, *medium* parts and *hard* parts

There were 47 students enrolled in the Spring 2025 course section. Figure 8 represents successful and failed submissions for all parts - *easy* (green), *medium* (blue), and *hard* (red) - from A2 and A3 combined. On the first attempts, many parts were rejected (dark green, dark blue, dark red) because the standard of excellence (threshold) defined by the instructor was not met. However, students were able to review and enhance their work within the required time window. The percentage of accepted files, including those that were rejected at least once, are shown for each assigned part (Figure 7). Students were successful in reaching the threshold after fast feedback from AGP.

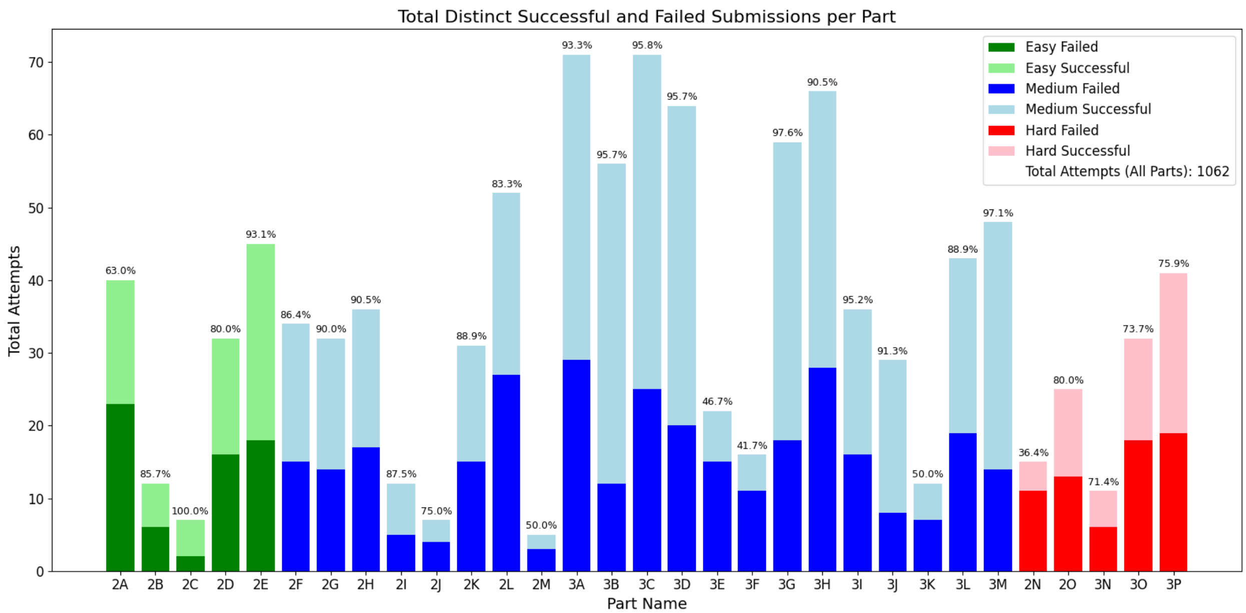


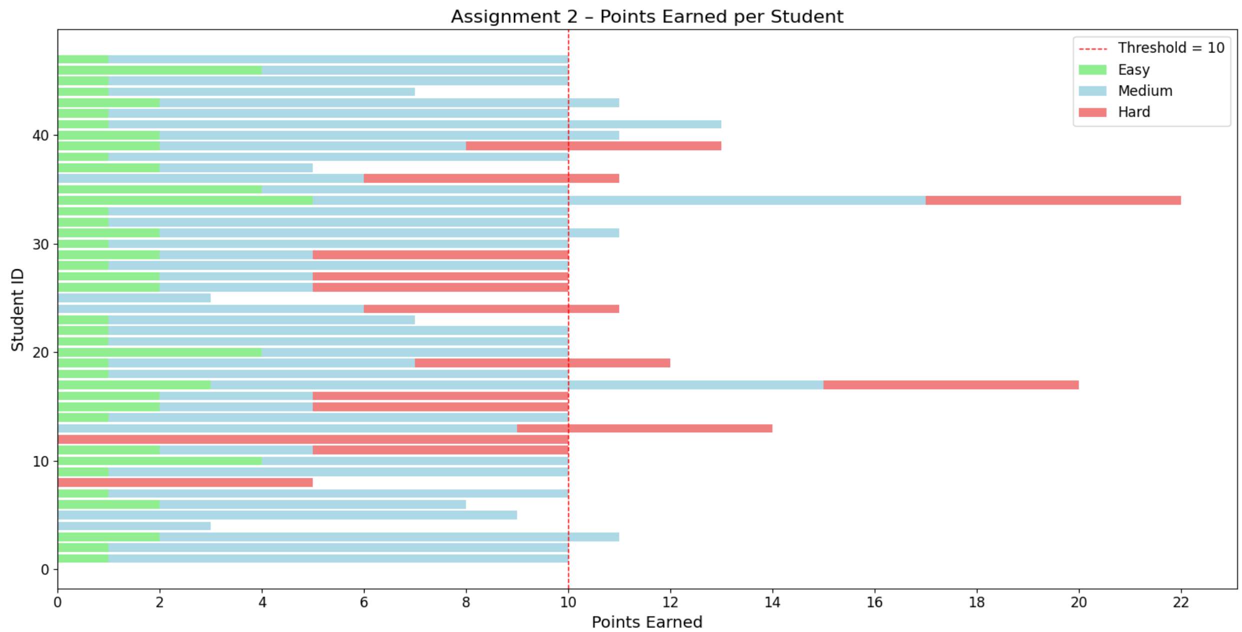
Figure 8: Total distinct successful and failed submissions per part.

The challenge in this approach is that there is no possibility of partial credit, but also no penalization for low-performing work, allowing students to continue working until reaching the threshold [21]. By doing so, students build and strengthen their 3D modeling skills.

The number of *hard* part submissions (red) were the smallest, as most models required a high level of proficiency that only some students achieved (fast learners). In this graph, A2 and A3 submissions total 1062 files, a volume that the instructor and two CAs could not manage without AGP. This highlights the impact of AGP on student learning by providing fast grading feedback while handling large numbers of files. It is important to note that human feedback is still necessary to support students. For instance, if a feedback states that the “shape is incorrect” and the student cannot identify the issue, office hours provide an opportunity for more detailed guidance.

Figure 9 shows points earned and part chosen by each student from assignment 2 (top) and from assignment 3 (bottom). In A2, 87% of students reached the maximum points (10 points) compared to 63% only reached the maximum points (30 points) in A3. In the latter, students were challenged, as they were required to earn more points and select *medium* and *hard* parts only. Given the number of parts to be made, the time window for

A3 was reduced compared to A2; yet 83% of students showed good performance by submitting 27 points or more. By the time A3 opened, students had already learned how to make feature-based models through class practice and assignment 2. TQM has been shown to affect student attitudes in the way to do the work [22]. When students begin to expect to do quality work, they pay more attention to details and optimize the time used to complete their assignments. Furthermore, some students exceeded the maximum point required for each assignment.



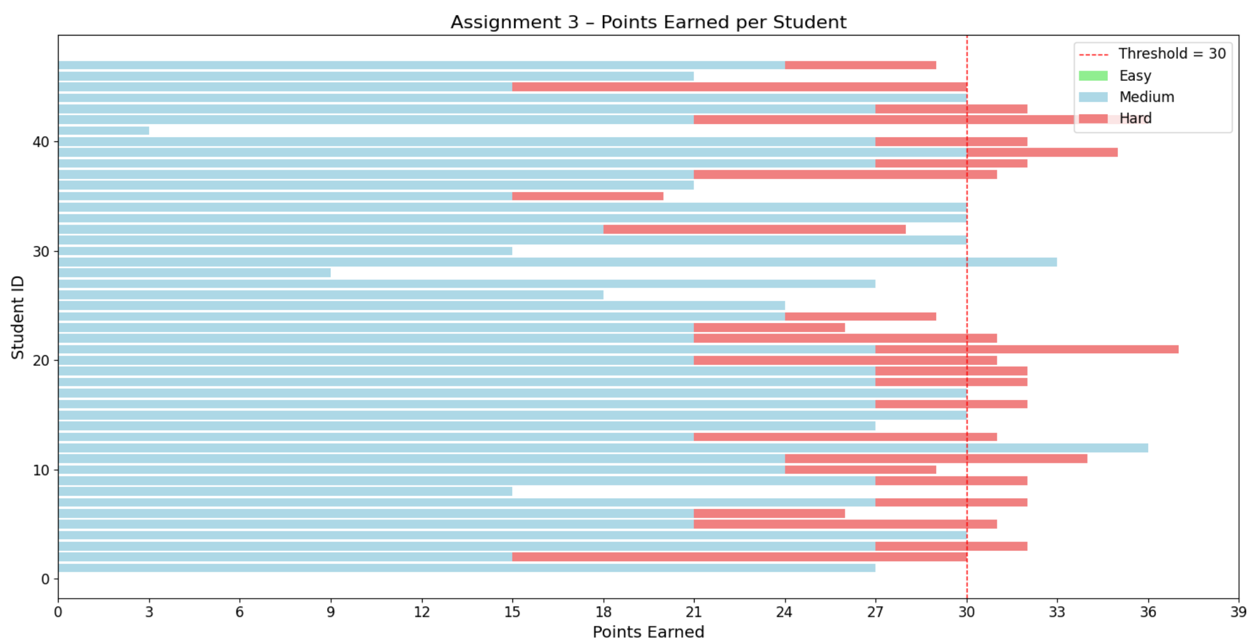


Figure 9: Part choice and total point earned by each student: in assignment 2 (top), in assignment 3 (bottom)

Figure 10 shows the time each student spent completing assignment 2 (left) and assignment 3 (right). Time is defined as the interval from the creation date of the first part to the last submission. Students who reached the maximum points (or more) for the assignment are shown in green lines, whereas students who didn't are shown with dashed red lines. The authors' intent is to evaluate students' work patterns in completing design assignments. Most students who began working on their assignment early (before mid-period) were able to reach maximum points for both A2 and A3. Among the 18 students who didn't earn maximum points in A3 (Figure 9), 10 started their first part in the last quarter of the assignment window (Figure 10). These students may not have allowed sufficient time to attend to details, correct mistakes, and develop work on new parts to reach 30 points. In the context of engineering education and the overall course workload in a given semester, some students may underestimate the time required to complete design assignments.

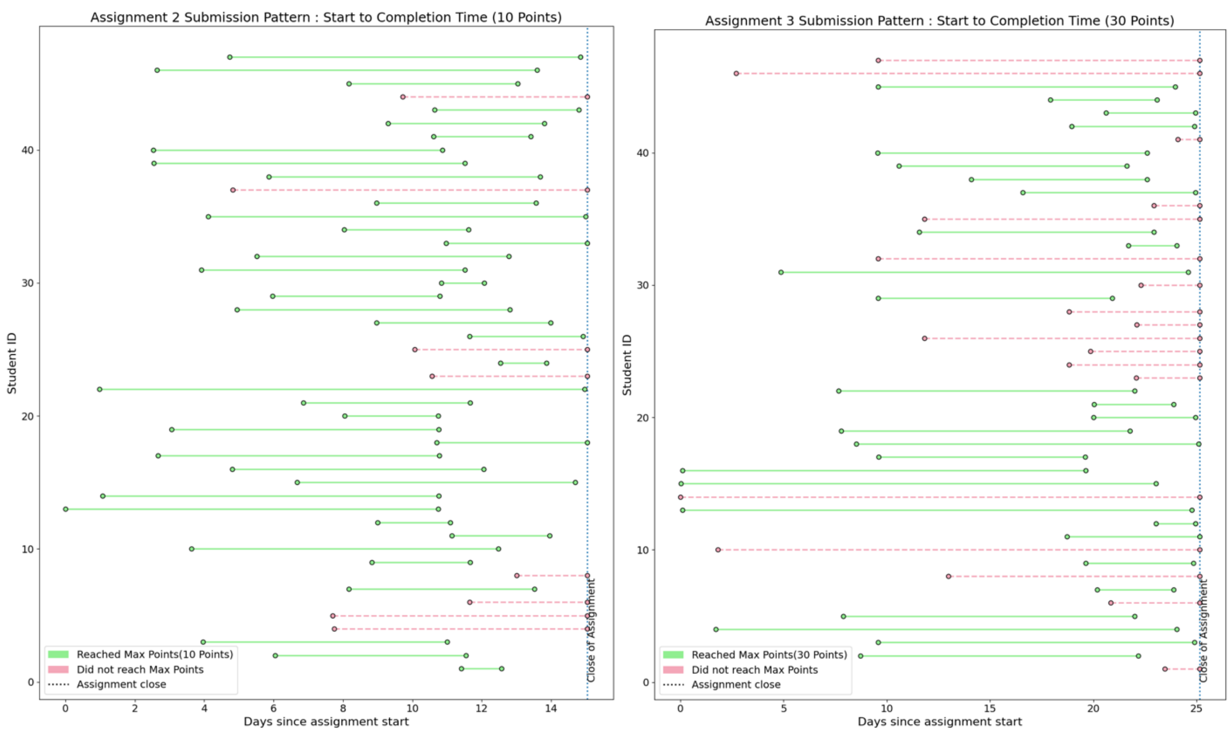


Figure 10: Start to completion time for assignment 2 (left), and Assignment 3 (right)

5. Students' opinions:

The instructor and course assistant received positive feedback overall. However, some students expressed the need of more specific feedback as they sometimes struggle finding their mistakes. Others didn't like the fact that no partial credit is allowed in the grading system and only exemplary parts are accepted. In Spring 2025 semester, a survey was conducted using the Learning Management System (LMS). Some students answered the following questions about AGP:

- **Upon submission on AGP, did it yield your expected output?**
  - *“Yes, it does the job”.*
  - *“Yes, I liked the detail of it saying what exactly was wrong with my part, so that I could fix it”.*
  - *“Sometimes it did but it always gave feedback in what may have caused the issue not why the part wasn't accepted”.*
  - *“Yes, it let me know if my part was correct or incorrect which was helpful for all the assignments”.*
  - *“It did yield an expected output. I expected to see some sort of feedback from the system and it did provide me feedback if my part was unaccepted”.*
  - *“According to what my instructor said, I knew what to expect”.*
  - *“Most of the times it would yield my expected output, but sometimes AGP would not accept my submission”.*

- **Please provide any additional comments (maybe to help improve AGP).**
  - *“AGP can provide instant feedback for real”.*
  - *“Overall, the grading response for a part on AGP is good”.*
  - *“AGP was very useful”.*
  - *“AGP was really fast on accepting on my part and giving some feedback”.*
  - *“Sometime I get a good result sometimes I make a mistake. Overall it's good”.*
  - *“I think AGP is good in mentioning things like undefined sketches, but is way too strict with how close your part has to be with the model part”.*
  - *“I think maybe giving partial credit could be helpful, but otherwise I think the grading platform works very well”.*
  - *“One thing that I think may be good to add, but isn't really necessary, is adding a submit all button to AGP so you can submit multiple parts at once”.*
  - *“AGP is almost perfect. If I have to say something to help improve AGP, I would say make the connection more stable. Anyway, AGP is good”.*

6. Conclusion:

An Automated Grading Platform (AGP) with immediate feedback directly to students has been developed and available at the authors’ university network. The instructor opens a course section on AGP and assigns work. Students register for the section and are able to see assignment requirements, submit work, and receive quasi-instantaneous feedback at any point within the assignment time window. The system is also suited for remote learning via a secure Virtual Private Network.

AGP is based on comparing the submitted part to a reference part and is in continuous development. It rejects any parts that do not meet the required threshold set by the instructor and counteracts plagiarism by detecting duplicate parts, allowing instructors to monitor academic integrity.

As a result, the system supports effective assessment and enables students to adapt their workflow to achieve course objectives. AGP has shown a positive impact on student learning outcomes and fostered a more interactive and formative learning environment, establishing an enhanced approach to teaching engineering graphics.

AGP uses deterministic algorithms for grading to ensure correctness and transparency. In parallel, AI-supported analytics are being explored to identify recurring student error patterns across multiple submissions and to support adaptive feedback and instructional insight, without altering grading decisions.

1. In case a student has a part rejected multiple times, a model can identify where the differences are compared to the reference part. If the student has a pattern of errors which they tend to repeat, a flag can be sent to the student through the notification system on the platform. The errors could be: "*using a material of the wrong density*", "*using the wrong unit system" …* etc.

2. At the end of an assignment, it might be helpful for the Instructor to identify parts which see a large number of failed submissions and identify where the students are making the mistake. Information about failed submissions can be fed to a model to identify patterns on where these students are failing and see if this happens across other parts as well. This is more from an analytics perspective to see where students are struggling.

In addition, the authors intend to expand AGP's capabilities to support grading of assemblies and drawing files. Furthermore, the authors see perspectives in building a customized "assessing design strategy" component on the platform for specific parts in which one optimum design process is accepted by the instructor.

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