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Balancing the Disciplines--Recalibrated

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Balancing the Disciplines—Recalibrated

Abstract:

This complete paper is a continuation of the work reported in the work-in-progress paper by the authors in the 2021 conference. Balancing the Disciplines is an interdisciplinary design project for use in Introduction to Engineering courses. At Dunwoody College of Technology, the course titled "Introduction to Engineering" is taken by electrical, mechanical, and software engineering first-year students. The team-based project involves designing, building, programming, and calibrating an electromechanical balance. This project makes use of the skills and interests of each represented discipline.

In the prior work ("Balancing the Engineering Disciplines!: An Interdisciplinary First-Year Design Project"), the authors laid out the project in detail and proposed changes to further improve the flow and educational value of the work. Many of these changes were incorporated for the fall 2021 course offering. This paper addresses those changes and compares student feedback results with the prior offering in fall 2020. Instructor feedback is included, and further refinements are also proposed.

Background:

Much effort has been expended in determining what helps engineering students persist in their education and in practice [1], [2]. Some have studied the impact of identity, gender, and stereotypes in engineering education persistence [4] and conclude that identity as an engineer is a bigger driver (than demographics and stereotypes) of persistence for first-year engineering students. One approach to improve engineering identity and outcomes for engineering education is the use of ill-structured design problems as put forth by ABET in EC2000 [5]. Work by Prendergast & Etkina [6] show the effects of making changes to accommodate ABET EC2000 improved student outcomes and produced successful engineers. There remains a gap between skills employers are expecting and the self-assessment of those skills by some populations as Rizwan et. al show [7]. Kahn & Novoselich [8] discuss using an independent design project to further development of engineering students' identities. Others [9] have studied the use of mindfulness training and psychological interventions to foster a sense of engineering identity.

Many first-year programs have some form of a design project included in early engineering courses. Most of these projects are completed in teams where the design work is constrained but still open-ended and ill-structured [10]. Shah [11] has worked to measure the development of design skills in engineering curricula and allow students to compare themselves to a class average. For example, spatial visualization was assessed and shared to enable students to gauge where they stand in relation to the class as a whole. The goals of these design activities are often to introduce the design process, allow students the opportunity to learn as a team, develop communication skills, practice project management, overcome the challenges that teamwork sometimes presents, and other less analytical skills that employers want [7], [10], [11].

The original Balancing the Disciplines project was introduced in the fall 2020 semester at Dunwoody College of Technology. The initial work was presented at the 2021 ASEE conference [12]. This work expands on the prior work with adjustments from the initial implementation and offers further adjustments to the structure of the project for future use. Based on the success of the offerings, it is a project we would recommend as it has minimal startup cost and achieves the interdisciplinary objectives for a beginning design project. Additionally, many of the principles from each discipline (e.g., programming, wiring) are at an entry level making the external support less challenging.

Balancing the Disciplines is a semester-long design project within the Introduction to Engineering course in which first semester students from electrical, mechanical, and software engineering design, build, calibrate, and test an electromechanical balance in interdisciplinary design teams of 3-4 students each. While it is impossible to ensure each team has equal representation from each discipline, the instructors strive to balance teams such that at least two disciplines are represented on each team. Milestone deliverables are submitted throughout the semester to keep the project moving forward. Class content, e.g., homework and lectures, is structured loosely around the design project to help scaffold the skills needed to be successful in the project.

The main changes made between the 2020 and 2021 offerings are grouped below into categories of project specific and overall course structure:

Project specific changes

1. The overall number of project deliverables was reduced by combining previous deliverables into larger ones with longer stretches of time in between due dates.
2. The number of opportunities to revise deliverables after initial submission was reduced as most 2020 teams chose not to utilize the revision option.
3. Students purchased a kit of common electronic components (Arduino microcontroller, breadboard, jumper wire, resistors, some integrated circuits, sensors, etc.) and the budget was reduced because of this cost being built in.
4. Students' initial concepts were individual. Teams shared concepts with the class after team forming. Previously concepts were not initially developed until after teams were formed.
5. To give teams more exposure to each other's concepts, design reviews were held in small groups during class (3-4 teams present) rather than a single team at a time with an instructor.
6. The point in the semester that required a physical build to be demonstrated was moved earlier to allow more time for troubleshooting and fine-tuning designs. This was completely unnecessary as we all know that students tend to start long projects well in advance of any due date or build demonstration.
7. Lastly, we removed the option of strain gages as this is close to an "off the shelf" solution.

Overall course structure changes

1. Due to an institutional change of the academic calendar, the semester length was reduced by two weeks.
2. In 2020, due to the challenges of COVID-19 and social distancing requirements, the authors individually taught small sections of approximately 9-12 students each with a total of three sections.
3. With the relaxed requirements during the 2021 school year, a single class section of 28 students was co-taught by the authors.

The question for this work is whether the changes made from the 2020 offering to 2021 improved the attainment of the objectives for the team project. There are three main objectives for this project (and projects in first-year courses in general share these or similar objectives).

The objectives are:

1. Students learn about the various engineering disciplines by applying them in a design project.
2. The project should be engaging and enjoyable.
3. The project should be team-based to facilitate the interpersonal skills such as teamwork, communication, project management, and other skills necessary to be successful in an engineering profession.

Project definition:

In this iteration of the Balancing the Disciplines project, the semester length was reduced from 18 weeks (as in prior years) to 16 weeks as the college has added a J-term and adjusted the fall and spring semesters accordingly. As a result, the course is two weeks shorter than in previous years. The overall structure and requirements of the project remained similar and are given below:

> Each team will design, build, calibrate, and test an electromechanical balance. The balance will not be purchased as a kit or as a pre-built off-the-shelf unit, e.g., no load cells. Strain Gages are also not allowed for this project. On the day of testing, the team will receive a series of items to weigh (within a predefined range). After receiving the items, the team will demonstrate their calibration procedure and weigh the items in a predefined order. The overall best in show (based on accuracy) will receive bonus points!
>
> Design Requirements:
>
> The following requirements apply to the design:
> 1. The balance shall be original to the team. Use of ideas from other solutions are encouraged; wholesale copying is not.
> 2. The capacity of the balance should be at least 1500 g.

a. The smallest mass will be approximately 50 g.

3. The measurement area should accommodate a 4” x 4” x 4” cube placed on a platform.
4. The balance will have a digital readout of the mass in grams to a tenth of a gram (e.g., 489.3 g).
5. The budget for the balance is $45. This budget is in addition to the Arduino kits that were purchased for the class. A project accounting record is required to demonstrate that your team didn’t exceed the budget. If you provide your own components without purchasing them, e.g., sourced from home or on campus you must still put a reasonable value to the item. E.g., how much does it cost at the local hardware store or Amazon?

The Arduino kits mentioned in item 5 were a required class supply. A parallel effort included work to develop class materials and homework assignments that did not require purchasing a textbook. The money students saved by not purchasing a textbook was allocated toward the Arduino kit and a multimeter to serve as tools in this course and in follow-on courses in circuits, mechatronics, and similar courses. The milestones for the project are provided in Table 1.

The designations PR1 and such indicate that this is a PRoject assignment. It also became a helpful way for students and faculty to discuss assignments coming due, such as, “We’re working on PR3 tomorrow, right?” or “Don’t forget that PR4 will be due next week on Wednesday!”

Table 1: List of project milestones and due dates

Week	Deliverable	Description
4	PR1	Project Concepts
5	PR2	Concept Selection & Project Schedule
8	PR3	Project Update and Force Demonstration (Build)
11	PR4	Design Review
15	PR5	Project Testing
16	PR6	Final Report & Presentation

The first deliverable, PR1—Project Concepts was an individual assignment. The approach to this deliverable differs from the 2020 offering which was a group submission. Each student individually developed three unique concepts that (sometimes) met the requirements. Teams had not been formed yet at this point, so there was no considerable cross-contamination of ideas as the students didn’t know who else they would be working with. All other deliverables were group submissions. The project in its entirety was worth 240 points or about 25% of the course grade.

There were also some incentives created to spur healthy competition and camaraderie. Namely, the team that developed the most accurate build (as demonstrated on test day) earned a 10-point bonus (~4% of the balance project or 1% of the class grade). Further, if more than ½ of the class had a balance that functioned (defined as reading a signal, processing it, and displaying a result that changed with changing masses) all teams (even those without functioning builds) would receive a 10-point bonus. The hope was that teams would more readily share tips and tricks that helped them overcome various obstacles if there was this camaraderie bonus.

Example builds:

There were several types of builds. Many employed springs and some distance measurements. Several used potentiometers to generate a signal corresponding to the mass. One used displacement of water to mass the object(s). Photos of example builds are provided below.

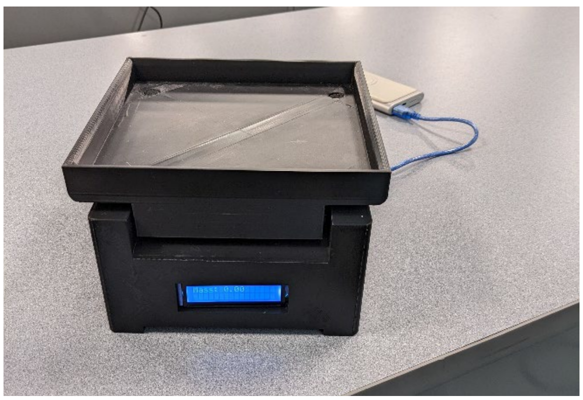

Figure 1: A balance utilizing a force sensing resistor in an enclosure

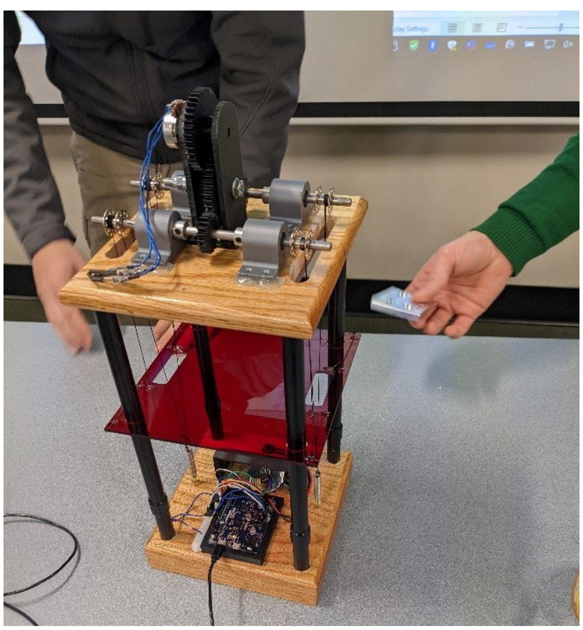

Figure 2: A design using springs, pulleys, gears, and a potentiometer

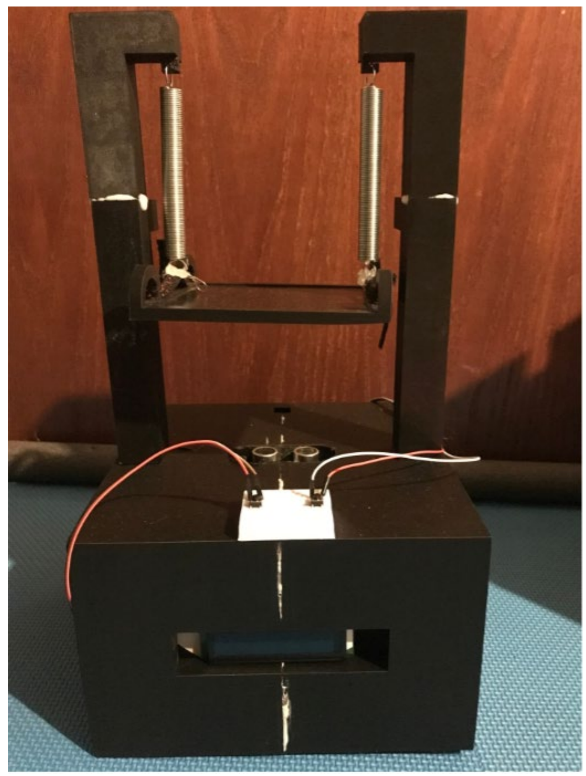

Figure 3: A suspended design using an ultrasonic distance sensor

Figure 4: A platform using a linkage and potentiometer enclosed in a 3-D printed housing

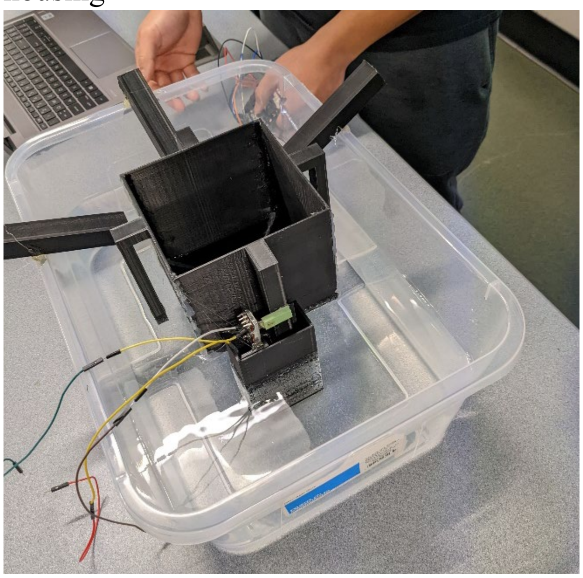

Figure 5: A water displacement design using a potentiometer and rack and pinion to generate signal proportional to water displacement

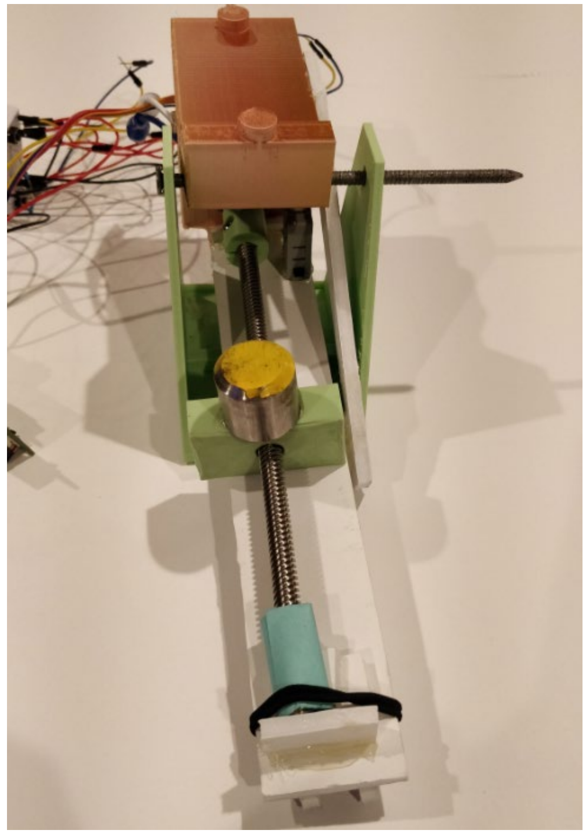

Figure 6: A balance using a stepper motor and balance switch to calculate moment for equilibrium

Objectives and methods:

As mentioned above, the objectives for this project are severalfold. First, we want students to learn about the various engineering disciplines in the context of design. Second, we wanted an activity that students would find engaging. Third, we wanted a team-based activity that would promote teamwork, communication, project management, and other skills necessary to be successful in an engineering career.

The authors collected data on the attainment of these objectives in a quantitative way using a series of prompts on a survey which students responded to using a Likert-like scale. A qualitative approach was also employed in which longform responses on the project in general were solicited on the Final Exam in the course. The survey was similar to the survey administered in Fall 2020 apart from an added question (prompt 9 in Table 2 below) on the usefulness of opportunities to revise prior deliverables after receiving feedback and initial grading. The prompts were designed to evaluate the project objectives as indicated in the final column of Table 2.

The prompts for the 2021 survey were:

Table 2: Prompts for quantitative survey

Prompt Number	Prompt description	Project Objective Link
1	The project helped me understand how different engineering disciplines work together.	1
2	I learned more about my discipline from the project.	1
3	I learned more about other disciplines through the project.	1
4	I learned how to learn new skills through the project.	
5	If given the choice at the start, I would do this (or a similar) project again.	2
6	The project helped me work on a team more effectively.	3
7	I grew my communication skills through the project.	3
8	I developed an understanding of how the engineering process is applied.	1
9	I wish there were more opportunities to revise initial deliverable submissions.	
10	On a scale of 1-5 (5 being the best) I rate the project as a ____ overall.	2

Results:

Quantitative Results:

The response rate for the survey was 76.9% (20 students responded out of 26 who were enrolled at that point in the semester). Students were instructed to rate each prompt on a 1-5 scale with 5 being strongly agree, 1 being strongly disagree, and 3 being neutral. The box and whisker plot provided in Figure 7 shows the results for 2020 and 2021. There is a small decrease in most responses for the 2021 results though the general trend is similar for both years. Overall, the students felt the design project met the goals we intended.

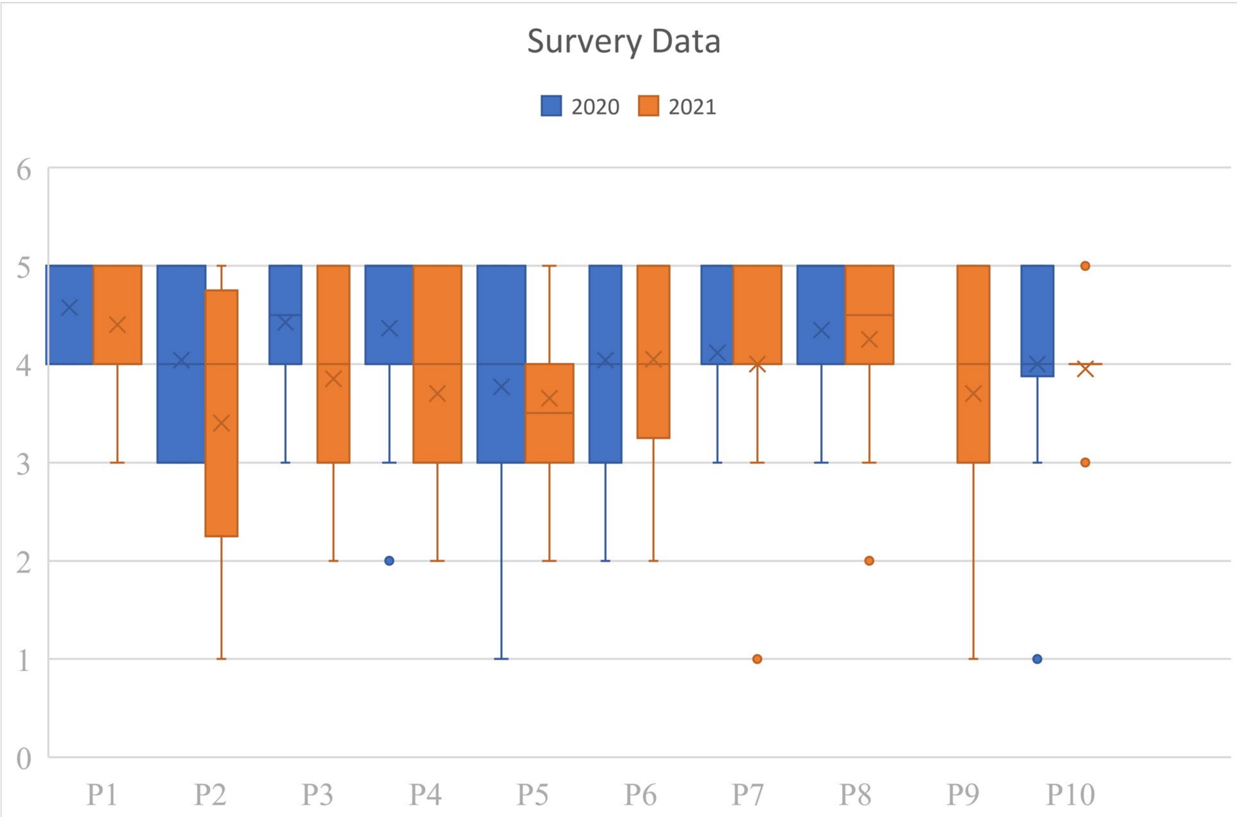

Figure 7: Box and whisker plot of student survey results from 2020 and 2021 offerings

<u>Qualitative Results:</u>

Students were asked, “What are two aspects you would recommend keeping and why? What are two aspects that you would like to see changed and why?”

Selected student responses for the <u>keeping</u> question are quoted below:

- I enjoyed the multiple skills that are needed for the project.
- I would like to keep the group co-operation aspect of the project, for it encouraged teamwork and co-operating between all groups in the class.
- I would also keep all the PR deliverables, as they kept groups on track with the project.
- I enjoyed having an entire semester to plan and build our project
- I would say overall it was good. everything about the project was fun.
- Though it was tough, learning things on the go forced us to learn a lot over the semester - at least for me
- The idea of the scale project. I felt that it was a good mixture of software, electrical, and mechanical.
- The scale project because it dementrates [sic] the process of making something.

- I would also keep the budget as is. It was difficult at first trying to figure out what we had to get and make ourselves to keep the project under budget but once we figured it out it worked great. It is a hard challenge but not impossible.

Selected student responses for the changing question are quoted below:

- Maybe allow for more of a redesign phase if a group wants to change their design completely
- We only learned the basics of the Arduino with inputting some basic code on to get some things to work on it. With us needing to have a digital readout most of our time has gone into trying to figure out how to code it.
- I would maybe add one or two more days to be able to work with the group in class, as sometimes it's difficult to meet outside of class, so it made it harder to work on the project together.
- I would also decrease the budget as our team didn't come close to spending it all.
- I would make the budget a little bit bigger.
- I would show current students designs from the past classes to spark some ideas or set a standard.
- Maybe a little more distribution in making the seems [teams], like if possible someone from each career in a team.
- Change the presenting of the PRs to the small groups instead of huge groups. I liked how in the small group presentations it seemed like people asked more in-depth questions about the project instead of trying to get it over with.
- Spend more time on what makes a good schedule and how to divide task up.
- I would change how often we got to work in class or compare to our peers our designs. So we could get help from others on how to improve and get help from the professors.

Discussion:

The quantitative results indicate that most students found the project helpful and useful in meeting the objectives it was designed to meet. Comparing the data from 2020 to 2021 show many prompts were similarly rated between the two offerings. The biggest differences were in prompts 4, 2, and 3 (in that order) in terms of the overall average and the amount of spread.

The qualitative feedback is similar between the two offerings. Both sets of students stated that they enjoyed the multidisciplinary aspect, the use of "PR" deliverables to keep them on track, and the process of designing and building something from start to finish. Overall, it appears that the students felt the project did help them understand their discipline (2), learn about other disciplines (3), and learn how to learn new skills (4).

There are a few notable differences between the 2020 and 2021 offerings. The 2020 course was split into three small sections to promote social distancing in what was a peak of the COVID-19 pandemic. Each author taught one or two sections in 2020 with 9-12 students in each section. In

2021, both authors co-taught a single, larger section. This larger format and less “face-time” with the instructor may have led to some of these differences. As noted earlier, the 2021 semester was also two weeks shorter than the fall 2020 offering. Further, the fall 2020 students may have been more relieved to be in-person and doing engineering design work after a few months of distance learning and remote instruction and found the format of the course and project refreshing. The 2021 class may have been fatigued by the pandemic and in general seemed less engaged in their studies than the previous class (even in other courses within engineering that semester).

Recommendations:

As a result of offering this experience a second time, there is not much further we would change. Based on the difficulty of keeping track of deliverable resubmissions, the relatively low participation rate in using this opportunity, and the low rating in the survey we do not intend to offer resubmission of deliverables in the future. Overall, the Arduino kits were beneficial and simplified ordering logistics though it reduced some creativity in what sensors teams utilized. We may add a requirement to use a device or component that was *not* included in the kit to get some other components and exposure to finding information typically found on datasheets or supplier websites. We have also considered adding creativity points instead of accuracy or possibly in addition to the accuracy bonus.

As noted in some student comments, it would be beneficial to have more class-time to work on the project. It is a careful balance to blend instruction, working in teams, and deliverables. Further, the smaller audience design review format worked very well. In larger class presentations, other teams were not as focused and engaged in the team presenting as they were when the class was split into two groups for design review presentations. An approach to address both issues is to have design reviews with a subset of the course while the remainder work on their projects in teams.
Some administrative improvements are to limit the course deliverables for a given week and have a regular cadence. With other course homework, the project, and activities there were often weeks with two assignments due that may or may not be related.

Adding some minor assignment to encourage attentiveness during presentations would offer some benchmarking to other teams and offer some constructive feedback for the presenters. The instructors could then compile and submit the feedback anonymously to the presenting team for consideration.

The Balancing the Disciplines project has been a success the last two years it has been offered. The authors plan to continue this project and collect additional results over the next several years.

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