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Interdisciplinary Engineering Project: Experimental and Numerical Optimization of a Sandwich Panel*

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A teaching-learning experience focused on the promotion of specific transversal competencies (self-learning, efficient oral and written communication and team working) integrated into the curriculum of Bachelor in Industrial Engineering (BIE) is presented. With the aim of reinforcing some traditional lacking aspects in old engineering curricula, some core subjects linked to project-based learning activities have been included in the new curriculum of BIE given by the School of Engineering of Barcelona (UPC). The current curriculum includes two mandatory subjects aimed to the acquisition of professional competencies. Students can choose from a list of fifteen available projects. An example of the type of projects offered on the course is given here. It is an interdisciplinary project combining Mechanics of Materials, Statistics and Engineering Project disciplines. Teaching learning methodology and benefits of the approach followed for promoting professional skills are presented. The final section summarises the main results provided by the experience against conventional activities.

Keywords: interdisciplinary project; engineering; professional competencies; problem-based learning

1. Introduction

1.1 The curriculum in industrial engineering

The curriculum in Industrial Engineering given in our School has its origins, as the School itself, as far as 1851. Obviously it has evolved a lot since then, but always keeping its basic objectives: to be a multidisciplinary engineering, with a very solid scientific basis, with a wide and transversal formation in basic technologies, with a good knowledge of economy and business administration, and with the possibility of specialising in some concrete technological area.

This type of curriculum allows the graduates to develop their professional career in many different areas of the industry, services and administration; and, equally important, they are able to easily adapt to changes in their activity and to rapidly assimilate, implement and promote the use of new technologies.

1.2 Strong and weak points of our graduates

During the year 2008, and due to the imminent need of changing the curriculum, to adapt it to the EHEA (Bachelor and Master Structure), the School decided to do a study on the Strong and Weak points of the profile of the engineers graduating from our School. The study was realized with the support of the Accenture Foundation, and included asking their opinion to professors, graduates, companies, employers, etc.

The conclusions were that our graduates have several relevant Strong points (like: good scientific and technical knowledge, motivation, learning capacity, working capacity, analytical capacity and versatility) and also several relevant Weak points (like: low experience in team working, bad interpersonal relation abilities, low initiative in problem solving, weak in oral and written communication).

1.3 Projects: a tool for improving abilities

With the objective of improving these Weak points several courses based on projects have been introduced in our curricula at Bachelor and Master level. We have differentiated three types of courses:

- PBL (Problem Based Learning): Courses where learning is almost exclusively based on PBL methodology, like Basic and applied Computing, Computer Aided Design and Project Management.
- PjBL (Project Based Learning): In courses like Project I, Project II, Final Bachelor Project, or Final Master Project, the objective is to learn to apply knowledge already acquired in other courses and to consolidate it through the application.
- CDIO (Conceive, Design, Implement, Operate): In the Bachelor curriculum there is a 12 ECTS block, and in the Master curriculum a 18 ECTS block, that can be fulfilled by participating in CDIO Projects organized by the School. A program called *Fet a l'ETSEIB* (Made in ETSEIB) offers to the student the possibility of participat-

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ing in different projects, like the *Forum Engineers* (a career fair), Formula Student (designing, building and driving a formula car for a University competition), Moto Student (designing, building and driving a sports motorcycle for a University competition), Smart Moto Challenge (designing, building and driving an electric urban motorcycle), RC Sailing (designing, building and sailing a scale sail RC boat), etc.

1.4 The mixed method

After long discussion, finally a mixed learning method has been implemented in our School, which combines efficiently different types of learning methodology: the most conventional (theory and problem classes), the more participative (seminars and workshops) and the most active for the student (PBL, PjBL, and CDIO). In our opinion this mixed method is the one that gives the best results, because it allows to find the adequate balance between the scientific rigor and the own research initiative of the student, between the guarantee of the desired knowledge level and the stimulus to get motivated, between the discipline of the programmed work and the motivation to implement the own ideas.

2. Teaching learning methodology

2.1 Description of the subject

One of the subjects introduced in the Bachelor of Industrial Engineering (BIE) in order to improve some specific transversal competences for future engineers, is Project I, a PjBL course.

Project I is taken by 220 second-year engineering students each semester. Because of this high number of students, the School offers twelve different projects. For each one, a minimum of 15 and a maximum of 20 students are allowed. The selection of the projects is done by the students in function of their academic reports. All the different projects have the same generic competences:

i. Autonomous learning.
ii. Oral and written communication.
iii. Team work.
iv. Initiation to real/complex engineering projects.

The generic competence (iv) is really important because allows the development of relevant skills for engineers like forming judgments or decision making. Six of the projects offered by the School are interdisciplinary because most of the real engineering problems involve several fields of knowledge. One of these six projects is *Experimental characterization, numerical simulation and optimization of sandwich panels*, which combines Mechanics of Materials, Statistics and Engineering Projects disciplines. The main goal of this course is to optimize the composition or the size of sandwich panels for a real application from a structural point of view. The next parts of Section 2 describe the implementation of PBL environment for *Experimental characterization, numerical simulation and optimization of sandwich panels*. The explanation is focused on different typical problems for PBL activities [9].

2.2 Working groups

The students that participate in the project are divided into five work groups. Each work group is formed by 3 or 4 students, so it is easier to individualise marks for each group member and to avoid the appearance of free riders or *parasite* members.

The groups are not formed randomly. The composition of each team is properly selected in order to make them more homogeneous. Therefore, all groups fulfill the following requirements:

- At least one member of the group courses or has coursed the subject of Statistics.
- At least one member of the group has coursed the subject of Numerical Methods.
- At least one member of the group has coursed the subject of Materials Science.
- If there are students from another Bachelor (Chemical Engineering or Materials Engineering) they will be mixed in groups with students from Bachelor of Industrial Engineering.

2.3 A real case of study

A good motivation increases the benefits of PjBL methodology. In order to motivate all students is recommendable to solve a real project. As a result, they observe that all the knowledge learned at university is useful and necessary. Moreover, real-life problems usually have multiple solutions and this tends to increase the creativity of the students.

The engineering problem to be solved is changed every year to avoid repeating projects and limit possible copies. All the problems done are a flexural optimization of a sandwich panel; therefore the first and the second milestone explained in section 2.4 do not have to be changed every course. As a result, it makes possible to implement different real problems without increasing excessively the course preparation. This year, a surfboard is analysed.

In order to avoid copies between teams each group has a different composite material (polystyrene resin with different glass fibre reinforcement) for the face sheets to build the sandwich panels. Nevertheless, all groups use the same extruded polystyrene foam for the core.

Fig. 1. Tensile test on coupons made from flat polystyrene plate.

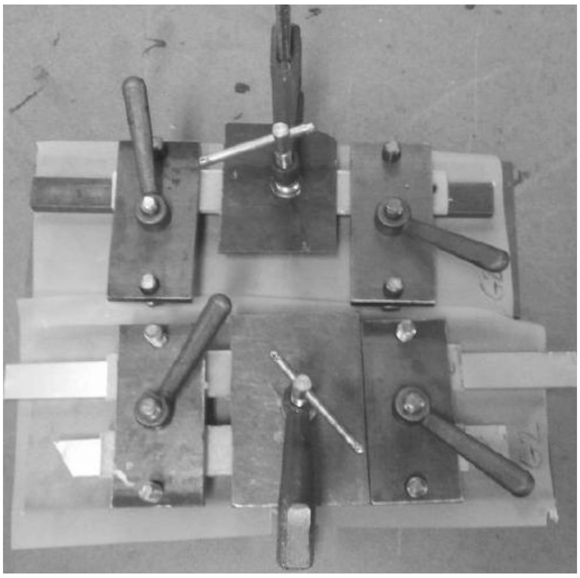

Fig. 2. Tools used to build the sandwich panel.

2.4 Planning and track progress

The correctly planning of the tasks is a key factor for a successful PjBL implementation. The duration of the project is around three month. We decide to introduce a milestone at the end of each month to improve the student-teacher interaction by the feedback of the deliverables. Moreover, the milestones allow students to focus on the main tasks and to organise better their work.

For the first milestone, students have to do lab work. They can observe the relationships between theory and practical work and they learn the importance of doing experiments to acquire data to solve problems [10, 11]. They do several tensile and flexural tests from flat polystyrene coupons reinforced with glass fibre to obtain the Young's modulus (Fig. 1), the yield strength and the ultimate tensile strength. They also do a shear test from the foam used to build the sandwich panels. Most of lab tests are done outside class hours, so they must plan with the lab technician the schedule for doing all tests.

For the second milestone, students have to build the sandwich panels (Fig. 2), do the flexural tests (Fig. 3) and simulate the flexural behaviour through a finite element analysis (FEA). The data obtained in the first milestone is used to describe the materials behaviour for the FEA. Once the simulation is done, each group compares the finite element results with

Fig. 3. Flexural test on sandwich panel (three-point bending test).

experimental data in order to validate the developed finite element model. At this point, the student-teacher interaction is necessary to obtain good results.

For the last milestone, students have to optimize the size of the face sheets and the core of the sandwich panels for a surfboard by FEA. The main goal is to obtain a good flexural stiffness with a minimum surfboard weight.

2.5 Assessment criteria

A 75% of the final mark comes from a group assessment and the other 25% from an individual mark. It is advisable to differentiate the marks inside teams to encourage all group members to get more involved in the project.

For the first and second milestone, every group makes an oral presentation. Only one group member, chosen at random, makes it. The rest of the group is responsible for answering the questions of the teachers. Furthermore, every team has to deliver a report in order to assess the written communication. For the last milestone, the oral presentation is divided up between all the team members.

The individual assessment is obtained through several theoretical questions done along the course and the answers of the oral presentations.

3. Actual benefits of the approach followed for promoting professional skills

Engineering students need to have better professional skills [2], such as written proficiencies, oral communication expertise, team working, problem solving, numeracy and IT skills, and self-learning [1]. These skills cannot be acquired in traditional classroom.

3.1 Promotion of specific transversal competencies

In this project students are sub-divided in working groups of three members (exceptionally four). The different composite material used for each group—mechanical properties and geometrical dimensions—, provides independent results between groups. That means each group has its own project in some way. For a start students face some challenges: information search (the nominal characteristics of the materials) and handling lots of data (the geometrical dimensions of the specimens).

All that is really a challenge for 2nd year students, who have barely studied other subjects than Mathematics and Physical Sciences in the first semesters; and these courses are usually taught in traditional classrooms, with a syllabus and lesson planning strictly enforced, and an assessment system based on written examinations.

They have to organize and manage the execution of the project. This includes work planning, meeting organization, and assignment of roles and responsibilities to group members. They will have to make decisions and come to agreements, and try to settle some possible friction between them as a consequence of discrepancies regarding the tasks assigned, working schedule, dedication, personal motivation, approach, and so on. That is:

- Self-learning
- Team working

skills, among others, are contextualized through the project development.

Students have a sense of freedom to face challenges in solving the problem and realize they are in control of the outcome, are more proactive and take the initiative. They take an active role and know the success of the group depends on all its members.

The first effort they need to do as a group is to know each other and try to get on well with their teammates. Some students do not like group working, but rather prefer work alone. Some subjects may be learnt well alone, but for other subjects, students may benefit from working in a group; which, without a doubt, can help students to get along in the future professional environment.

Then the laboratory tasks are undertaken. Previous experimental testing, geometrical measuring on samples must be taken. Now students must take their first decision: which and how many measurements are required and/or useful? This could be a statistical question. It is time for one Statistics class to learn how to apply statistical tools to the experimental data collected. It has to be pointed out that these students take a Statistics course in the current semester, at the same time that they do *Project I* subject. They have to prepare a data file with a structure suitable for statistical analysis, so it has to decide how to organise data in a spreadsheet. They can discover how something as simple, but annoying, as the fact that the number and/or size of rows and columns in tables might be different than expected.

The experimental tasks include the manufacturing of the sandwich samples, which is made by the students themselves. The samples must be well glued. Manual ability, care and attention paid on this important phase will affect the experimental test results. They know that. The tensile, bending and shear samples made from individual material had been made previously.

A final year student, under the guidance and supervision of laboratory technician staff, helps to project students in performing mechanical testing of samples, which has a positive effect on them, since it inspires confidence and gives them a freedom sense of proximity, closeness and personal attention.

They need to apply their acquired knowledge in Material Science course taken in the third semester, and it would be advisable to have studied Continuum Mechanics and Strength of Materials, but these disciplines will not be seen until the fifth and sixth semester respectively. An indication of these contents is given and they will do the rest themselves.

3.2 Acquisition of other professional abilities

Now is the time to prepare the first preliminary report. This involves deciding how the information and outcomes are to be displayed: contents, organization, presentation, explanations, bibliography, and so on. Each team is required to report and present their outcomes. Other professional abilities are developed in this part of the project, such as:

- Efficient oral and written communication
- Make a presentation
- Meet deadlines
- Answering questions.

Questions asked by teachers during the verbal presentation and suggests proposed provide feedback to students that can help them improve their work and also avoid repeating mistakes. It is necessary to insist on the fact that all figures and tables must be referred in the text.

Between the first and second reports there is a term to carry out the numerical analysis of the three-point bending test, by using finite element software (Ansys). Project-I students have some knowledge of Numerical Analysis given that they took the course on Numerical Methods in the previous semester (the third one). However, this is a new challenge for them because they never performed analysis with geometrical and material nonlinearities before, which requires a more complex analysis. This part of the course introduces and assesses the following professional competency:

- Problem solving skill.

After the presentation and submission of the second preliminary report, and before submitting the final written report, students take a second class purposely aimed at Statistics. The goal of this session is to analyse the parameters derived from mechanical properties of the materials. Both quantitative and qualitative statistical analysis by using the data collected will be performed in order to understand sandwich panel behaviour and undertake the final phase of the project: the optimization of sandwich panel design with geometrical constraints given in the statement of the problem. Numerical analysis provides responses on the panel behaviour as a function of the geometrical parameters of cross-section, once the finite element model has been validated against experimental results.

Throughout the project, students have been working with this software: MS Excel, Minitab and Ansys. It is good for students to practise this skill in context for their future integration to the workforce. Thus the acquisition of another competency is included:

- IT skills.

3.3 Multidisciplinary implementation

Graduate engineering students are expected to work effectively in teams and more specifically in multidisciplinary teams. To this end, the Engineering School at UPC has redesigned Engineering studies in order to include formalized instruction on how these multidisciplinary teams should function or interact. The approach has been successfully explored in [12]. Project I subject brings the first contact with interdisciplinary coursework and teamwork for 2nd year engineering students.

This type of subjects are commonly placed at the end of the studies, but it is important that contact with multidisciplinary groups occur early and repeat at several points of the engineering studies in order to ensure this key competence is properly developed and can be successfully applied in their future professional life.

In this subject, we decide to combine statistics and Material science in order to solve a real problem. It seems useful, and it is, because of the need of experimental data, their management, and their posterior analysis to optimize the final design.

3.3.1 Need for statistical analysis

Statistical thinking enables engineers to plan a good collection of data and performing a statistical analysis for transforming data into information for decision-making in the presence of variability of real-world problems.

In general, as stated in [13, 14] statistics education has usually been raised from a very general point, without clear links to the main or any particular engineering discipline. As a result, some engineering students have a lack of motivation for this subject and they do not acquire the full potential of statistical thinking.

The implementation and fit between engineering and statistics disciplines was fairly straightforward, as the proposed starting point was an experimental data collection from which students should be able to make valuable decisions in the sake of obtaining the final product.

3.3.2 Planning of statistical sessions

Two of the fourteen classes of the subject are allocated to statistics. The sessions were planned in order to introduce the statistical techniques as needed to continue with the project.

As a side note, most students were also attending Statistics subject concurrently with Project I, so that the difficulty of the sessions was aligned with those of the aforementioned compulsory subject.

The first session is planned at week 6, right at the end of data collection. The session consisted of two parts:

The first part tends to find certain values derived from taking the samples measures, such as density and area from a descriptive analysis of the data collected. This analysis is very simple but very useful to induce students to ask themselves questions related mainly to the quality and reliability of the data collected apart from the different calculations proposed.

In addition to finding errors in data collection and typical manufacturing defects, checks are performed on different nominal density samples based on experimental data. The technique used in this case is the Hypothesis Testing.

An additional academic result on this first part has been the use and need for data collection templates.

During the second part of the session linear regression is used to determine the Young's modulus in tensile tests. Students at this point are readily willing to discuss where to find the *linear part* from the analysis of the model residuals rather than ad-hoc approximation. Furthermore, students have to decide if the behaviour of the composite material is linear or nonlinear and how to characterize the stress-strain relationship for the finite element analysis.

The second session requires more advanced statistically and technically skills. This session has two different objectives. The first one is to analyse the mechanical properties of the composite (Young's modulus, ultimate strength, etc) in function of the quantity of glass fibre reinforcement. The second objective is to analyse the influence of some geometrical factors in the flexural behaviour of a sandwich panel.

3.3.3 Implementation results

The use of statistics in a course of this type has shielded very positive results. On one hand it has been instrumental to explain them in the context of a small engineering project and see its usefulness on a real field and on the other has been an ideal vehicle for learning statistics.

In many cases, students have been amazed at the power of a simple descriptive analysis for debugging a database and the amount of information that can be extracted from experimental data.

Students have appreciated the usefulness of the statistical techniques to a successful development of the project. They have also learned the utility of the entire project to acquire essential statistical thinking in their profession and they believe that it has been an excellent learning supplement for the standard statistics course.

The next section sets out evidence-based benefits from the experience on skills acquisition.

4. Main results

The first objective evidence of the effects of this methodology concerning the acquisition of skills is already observed during the course of this project. Table 1 shows the marks of the two last academic years from each of the four assessed parts: three group marks and one individual mark. (The range is: 0–4.9 F, 5–6.9 C/D, 7–8.9 B/A^-, and 9–10 A^+). In columns 4-5-6 can be seen the group work marks during the course regarding:

- Written proficiencies
- Oral communication expertise
- Team working

Column 10 shows how well the individuals within the group are working.

Later, when these students take subjects including experimental work and course project report, it has been proved that they retain more knowledge and know how to apply what they learnt back then. They write better reports, their communication is more fluent and they are easy to get along and create more effective oral presentations. These positive effects have been noted when students were enrolled in subjects given by the authors in subsequent semesters: Continuum Mechanics (fifth semester) and Strength of Materials (sixth semester).

4.1 Surveys and evidences

In order to study and analyse the benefits of PLB implementation to acquire professional skills, eighteen students answer a survey in the academic years 2011–2012 and 2012–2013.

From the surveys, we obtain that students perceive the following benefits:

- Preparation for future engineering jobs.
- They get used to work in groups.
- They learn how to use templates and write a formal report.
- They improve oral communication.

They learn how to organize tasks to reach the initial goals.

The number of students that perceive the main benefits of PBL can be seen in Fig. 4.

We also ask for the differences that they notice

Table 1. Marks (0–10 scale) obtained in the two last academic years.

	Group members	Group nr.	Group work marks			Individual marks			Course mark
			Pre-Rep1	Pre-Rep2	Fin-Rep	Questions	Attitude	Average	
Academic year 2011-2012	DQ	*1*	8	8	8.5			8.25	**8.3**
	FP							8	**8.2**
	OG							8.25	**8.3**
	SF							7	**8.0**
	BD	*2*	9	7.5	7.25			8	**7.8**
	CR							8	**7.8**
	GR							6.5	**7.5**
	TC							8	**7.8**
	BH	*3*	8	8	10			7.5	**8.7**
	HR							10	**9.2**
	SL							7	**8.6**
	CB	*4*	8.5	9	8.5			9.5	**8.8**
	GC							8	**8.5**
	RS							8	**8.5**
	AS	*5*	7	8.5	7.5			7	**7.5**
	MV							8.3	**7.8**
	TC							7.8	**7.7**
Academic year 2012-2013	CS	*1*	6	6.5	7.5	6.5	7.5	7	**7**
	LG					7.5	7.5	7.5	**7.25**
	MD					5	5	5	**6.5**
	AC	*2*	9	9.25	8.75	7.5	10	8.75	**9**
	CT					6	8.5	7.25	**8.5**
	OC					6	8.5	7.25	**8.5**
	BS	*3*	8	8.5	9	7.5	10	8.75	**8.75**
	BG					10	10	10	**9**
	MP					10	7.5	8.75	**8.75**
	MG	*4*	7	7.75	7	6.5	7.5	7	**7.25**
	PH					7.5	5.5	6.5	**7**
	WG					7.5	7.5	7.5	**7.25**
	UG					5	6	5.5	**6.75**
	BS	*5*	8	9	8.5	7.5	8.5	8	**8.5**
	SM					5	8.5	6.75	**8**
	TC					7.5	10	8.75	**8.5**

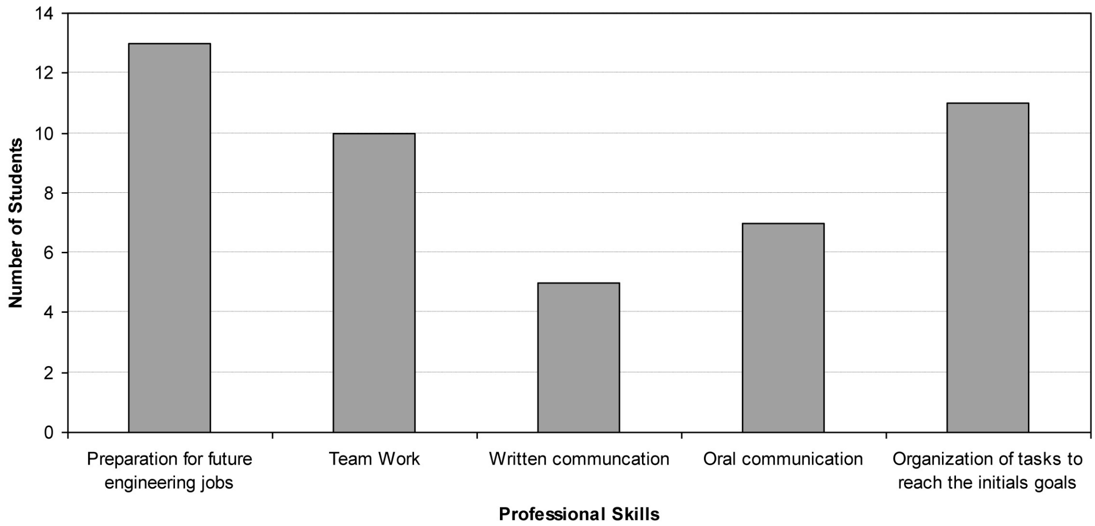

Fig. 4. Feedback from surveys conducted in June 2012 and June 2013.

between PBL and traditional learning methodology. Two main differences arise:

- They learn that the theoretical knowledge acquired is useful to solve real-life problems.
- They realize that real-life problems have multiple valid solutions. Moreover, they notice that the necessary data to solve a project are not usually given. In order to acquire this initial data is necessary to do experimental tests, statistics analysis, etc.

We also compare the course projects of Continuum Mechanics subject done by students of the old and the new BIE. We find the following differences:

- They make a better treatment of the initial data. They use experimental test, statistics tools, specific software, etc.
- They are used to solve real open-problems, so they tend to study different solutions analysing the advantages and disadvantages of each one.
- They use a more precisely and technical language. The quality of the reports, from a written communication point of view, has improved.

5. Conclusions and future proposals

The main conclusions, after two years of having implemented the Project I subject, could be summarised as follows.

In an Engineering curriculum, the mixed learning method (classic classroom theory and problem subjects, combined with PBL and PjBL subjects) provides the best results. It is important that contact with multidisciplinary groups occurs early, and repeats at several times along the Engineering studies.

The Project I PjBL course is a very good tool for acquiring transversal competences (autonomous learning, oral and written communication, team work, real complex problem solving), and helps much students in improving their oral and written capabilities and to use a more precisely and technical language.

A good motivation increases the benefits of PjBL. Solving a real-life project is a good way to motivate students. Students learn that the theoretical knowledge acquired is useful to solve real-life problems and that real-life problems have multiple valid solutions.

Students are amazed at the power of a simple descriptive analysis for debugging a database and the amount of information that can be extracted from experimental data. Students appreciate the usefulness of the statistical techniques for a successful development of the project.

The course has been performing well for over 2 years now with good results, but in a continuous improvement fashion is always possible to correct weaknesses and perform refinements. Some proposals to be considered for future academic years are as follows.

The first and foremost improvement is the inclusion of English in reports and presentations, to highlight another very important, basic cross competence in the learning of a future engineer: the use of another language.

Furthermore, we would like to incorporate a part of co-evaluation in various parts of the project. In this way students could see and appreciate other works and learn from it.

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