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# Problem-Based Learning (PBL) for a Construction Capstone Course: Assessment Through Competing Values Skill Surveys (CVSS)

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## Abstract
It has been widely recognized that traditional lecture teaching techniques in higher education may leave gaps in the skill development of students, especially soft skills. This gap can prove to be detrimental to graduating construction engineering and construction management students, as well as to their potential employers. But essential skills required to function effectively in the industry such as leadership, communication, mentoring, collaboration, and stress coping can be inculcated in students by implementing alternative teaching techniques such as Problem-Based Learning(PBL). It is therefore important to assess and quantify changes in soft skill development among students due to PBL.In this study, PBL was administered in a course titled "Construction Management Capstone" during the spring of 2015by the Department of Construction Management and Engineering at North Dakota State University. By using an assessment tool called Competing Values Skill Surveys (CVSS), it was concluded that PBL can have positive impactson certain soft skills, predominantly in collaborative and control-focused competencies, with some improvements in creative and competitive-focused competencies.

## Keywords
Problem Based Learning (PBL), engineering education, capstone, soft skills, CVSS

## Introduction
Engineering is the problem-solving application of basic science principles with mathematics. Instructor-centered teaching approaches have been traditionally used for higher level engineering education in the United States (El-adaway et al., 2014). But past studies have criticized such approaches for their inability to provide students sufficient context to comprehend and apply information in the real world (Schmidt, 1993). When students are passive receptors, teachers struggle to raise their interest based on theoretical and practical/laboratory sessions (Zeng & Xu, 2010) and, under such conditions, students do not typically get a chance to work in collaborative environments and therefore lack opportunity to hone their people skills. Considering construction, the industry demands faster and more cost-effective delivery of projects that are essentially achieved through fast-tracked, team-based approaches, such as design-build. Such situations will require collaborative teamwork from professionals to lead, innovate, communicate, manage time under tight deadlines, and cope with stress (Zeng & Xu, 2010). However, some of the traditional teaching pedagogy for civil and construction engineering and management programs are not much focused on the development of the above-mentioned "soft skills" in students (Walters & Sirotiak, 2011). There is therefore a need to explore alternative teaching philosophies in construction engineering and management programs.

In engineering education, capstone courses are intended to create a much-needed link between academic learning and professional experience (Jones et al., 2013). After the Second World War, capstone courses were designed to translate theory-based coursework into practices required by industry (Dutson et al., 1997). Prior survey instruments among teachers of such engineering capstone courses have revealed that the most important goal of a capstone project was to help students apply prior knowledge of courses in simulated environments of realistic, open-ended projects (Pembridge & Paretti, 2010). However, traditional lecture-based teaching techniques may not be able to translate such applicability of previously acquired knowledge (Sirotiak & Walters, 2012). It is therefore critical to think beyond traditional teaching techniques for engineering capstone courses.

Several alternative teaching approaches have been explored in the past to improve the effectiveness of the learning process, such as Discovery-Based Learning (Behzadan & Kamat, 2013), service leaning (El-adaway et al., 2014), and Problem-Based Learning (McIntyre, 2002; McLoughlin et al., 2015; Sirotiak & Walters, 2012). Also known as PBL, Problem-Based Learning is a widely studied and effective learning technique (Hung et al., 2008; Jones et al., 2013). However, while it is critical to assess and quantify potential changes in students' development of soft skills as a result of PBL in higher level classes, there is little published work assessing these changes to the best knowledge of the authors.

In this work, PBL was administered in a course titled "Construction Management Capstone" by the Department of Construction Management and Engineering of North Dakota State University. It was hypothesized that construction engineering and construction management students will show improvements in their collaborative qualities through implementing PBL techniques for a capstone course. One way to assess these improvements may be by the use of Competing Values Skill Surveys (CVSS), which are otherwise used in business-related disciplines.

## Methodology

### Participants

The participants of this study were undergraduate students of Construction Management and Construction Engineering programs in North Dakota State University, enrolled for the course CME 488 *Construction Management Capstone*. A total of 20 participants learned through a critical system administered with an underlying PBL philosophy. Subsequently, qualitative responses were provided by 19 students, based on which possible patterns were identified. The instructor of the course served as the facilitator.

### Class Assignments

The students were provided with loosely structured open-ended tasks as assignments for the course CME 488. One of the projects titled *Napkin Sketch Project* required students to develop complete ideas of their own when divided into groups of four or five. Conceptualized ideas of a structure, based on the initial napkin sketch, were then transformed into CAD drawings, electrical, mechanical, and structural load calculations, schedules, and estimates by the group to form complete bid packages and turned in to the instructor under strictly enforced deadlines. The instructor played the role of the client and the different groups represented contractors who were competing for a bid. Existing building codes and cost schedules from North Dakota, Minnesota, and Iowa were used as guidelines while developing the bid packages and the groups presented their work to the class at semester's end.

### Survey Instruments

The students were given the option to voluntarily fill out pre- and post-assessment surveys during the semester. The survey instrument used was CVF's model CVSS. According to Quinn, 6$^{th}$ edition (Quinn et al., 2014), different personality traits and complex actions can be categorized into four quadrant-based categories: *Collaborate, Control, Compete, and Create* (Figure 1a).

The upper left quadrant of the competing values framework marked as *Collaborate* reveals personality traits that lead people toward making connections and collaborations with others. Those excelling in this quadrant can maintain open and respectful communications because they tend to have better understanding of both themselves and others. These individuals are also effective conflict resolvers (Quinn et al., 2014).

The bottom left quadrant of the competing values framework marked as *Control* reveals the personality traits of maintaining stability and continuity. Those excelling in this quadrant can potentially become managers and effectively track whether colleagues are complying with rules and regulations. They are capable of managing varied tasks such as planning, coordinating data from various departments, and keeping up with minute details (Quinn et al., 2014).

The lower right quadrant of the competing values framework marked as *Compete* represents improvements in productivity and profitability. Those excelling in this quadrant understand an organization's vision as well as the environmental and external conditions under which tasks need to be fulfilled. Such individuals are task-oriented and work-focused, accept responsibility, and complete assignments in a timely manner (Quinn et al., 2014).

The upper right quadrant of the competing values framework marked as *Create* represents the ability to adapt to changes and acquire external support. Those excelling in this quadrant are mindful of changes in their surroundings and, moreover, can innovate and excel within existing trends (Quinn et al., 2014).

A person's inclination to exhibit traits of flexibility or control may influence the functionality of an organization, and improvement in performance sometimes depends upon organizational flexibility. Some organizations therefore engage in non-routine projects (Anantatmula, 2008) while, on the other hand, projects are often assigned with specific objectives and schedules to balance flexibility (Quinn, 2004). This quadrant-based assessment system can therefore reveal one's inclination towards flexibility or stability, but also one's inclination

towards external or internal functions. Some individuals are more inclined towards internal tasks (accounting, operations management, and supply chain management) while others are conversely better at managing external activities (resources and funding) (Quinn, 2004).

The questionnaires consisted of 36 questions for self-assessment and another 100 questions for assessment by others. Students completed these questionnaires before and after PBL assignments and some open-ended questions were subsequently asked, with qualitative responses.

The four quadrants include five competencies each. A score was assigned to each competency, which in turn was calculated from average scores of five questions as answered by the respondents. These scores could range from 1 (Never) to 7 (Almost Always). Quadrant-based competencies have been shown in Table 1.

## Statistical Analysis

Paired t-tests have been performed on the results from pre-test and post-test scores as prepared by the CVSS method. Analysis have been made by using SAS statistical software. A paired t-test is a statistical method, used to compare two population means. Assuming that the difference between the paired values is normally distributed, Student's t test is used to test the null hypothesis that the difference between population means is zero (Hsu & Lachenbruch, 2008).

**Table 1**: Competencies of Different Quadrants of CVSS (Quinn et al., 2014)

| **Collaborate**<br>*Creating and Sustaining Commitment and Cohesion* | **Create**<br>*Promoting Change and Encouraging Adaptability* |
|---|---|
| Understanding Self and Others (USO) | Using Power Ethically and Effectively (UPEE) |
| Communicating Honestly and Effectively (CHE) | Championing and Selling New Ideas (CSNE) |
| Mentoring and Developing Others (MDO) | Fueling and Fostering Innovation (FFI) |
| Managing Groups and Leading Teams (MGLT) | Negotiating Agreement and Commitment (NAC) |
| Managing and Encouraging Constructive Conflict (MECC) | Implementing and Sustaining Change (ISC) |
| **Control**<br>*Establishing and Maintaining Stability and Continuity* | **Compete**<br>*Promoting Change and Encouraging Adaptability* |
| Organizing Information Flows (OIF) | Developing and Communicating a Vision (DCV) |
| Working and Managing Across Functions (WMAF) | Setting Goals and Objectives (SGO) |
| Planning and Coordinating Projects (PCP) | Motivating Self and Others (MSO) |
| Measuring and Monitoring Performance and Quality (MMPQ) | Designing and Organizing (DO) |
| Encouraging and Enabling Compliance (EEC) | Managing Execution and Driving for Results (MEDR) |

**Table 2:** Competencies having Significant Improvements due to PBL and their P-values

| Competency | p-value (α = 0.05) | Quadrant |
|---|---|---|
| Managing and Encouraging Constructive Conflict | 0.0052 | Collaborate |
| Mentoring and Developing Others | 0.0170 | Collaborate |
| Organizing Information Flows | 0.0165 | Control |
| Planning and Coordinating Projects | 0.0129 | Control |
| Designing and Organizing | 0.0436 | Compete |
| Fueling and Fostering Innovation | 0.0390 | Create |

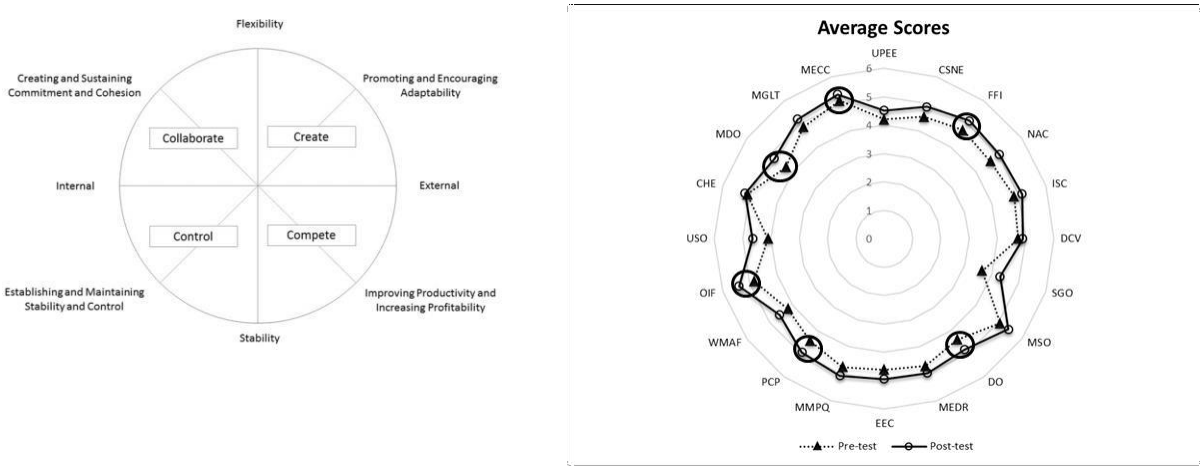


**Figure 1:** (a) Quadrant-based assessment system of CVSS (Quinn et al., 2014), (b) Pre-test and post-test average scores

## Results and Discussion

As can be seen from Figure 1b, out of 20 competencies spread over four quadrants significant improvements were observed for six competencies when compared between pre-assessment and post assessment scores (marked by black circles). These improvements were statistically significant, as confirmed from the paired *t* test, with a 95% confidence interval (Table 2). A p-value lower than the α value (0.05) indicates statistical significance.

The initial hypothesis of improvements in collaborative skills was proved to be correct by the results (MECC and MDO from Figure 1b). However, the research also showed added soft skill growth in several quadrants. Out of six competencies two each were listed in *Collaborate* and *Control* quadrants, and one each was listed in *Compete* and *Create* quadrants of the CVSS profile. This PBL process appealed more towards internal rather than external competencies when the class is considered as a work unit. Students of the class may therefore be assumed to be best-trained toward critical functions of internal operation, teamwork, leadership, communication, and organizational skills as a result of PBL. On the other hand, overall inclinations of the class towards stability or control seemed to be well balanced.

## Collaborate Quadrant

Significant improvements in two of the five competencies of this quadrant reveal that students in the capstone course become better collaborators because of PBL, developing traits enable them to work more cohesively with others and be better communicators. Open communication becomes possible because a state of mutual respect is developed among individuals. Mutual understanding, clear communication, and effective conflict resolution are indispensable for success in construction and other industries, and construction engineers and managers are expected to be leaders.

The development of mentoring relationships among groups is also very important in this industry, where a good leader is often a good mentor who in turn is often mentored by a more experienced individual. PBL in this study has evidently promoted at least conflict management and mentoring capabilities skills among students, and this effect is detected and quantified by CVSS.

### 3.1.1. Managing and Encouraging Constructive Conflict

The first significant competency in the Collaborate quadrant is Managing and Encouraging Constructive Conflict. Conflict is an inevitable reality among the ranks of the workforce in an organization (Tjosvold et al., 2014), may be destructive or constructive (Deutsch et al., 2011), and can be important in organizations to break the stagnancy and monotony of work groups. But while constructive conflicts can promote critical thinking and innovation (Rolih, 2013), destructive conflicts may potentially be devastating to individual team members.

One of the key factors for managing conflicts as discussed by past researchers is the definition of conflict itself (Rolih, 2013; Tjosvold et al., 2014). Conflict has often been confused with confrontations under conditions of opposing interests, or a lack of common goals among team members (Pondy, 1967), or with competition (Deutsch, 1973). However, conflicts can arise among team members with common interests and goals. For example, in a construction engineering setting, team members can interpret plans and specifications of a project differently and therefore may have different approaches to completing tasks. There may also be conflicts between team leaders and team members about such matters as work volume. Conflict management skills are therefore important for construction engineering and construction management graduates, and there is a consensus among past researchers that the path to conflict management is through open or open-minded communication (Rolih, 2013; Tjosvold et al., 2014). There needs to be a certain level of mutual benefit in decision-making for open communication to flourish among team members (Tjosvold et al., 2014), who also need some level of emotional intelligence to be effective conflict managers and promoters of constructive conflict (Schlaerth et al., 2013).

Since significant improvements in the competency pertaining to managing and encouraging constructive conflict were observed in the present study, it is evident that PBL is an effective promoter of such skills among students. Further, such changes in the personality of students could be well-quantified by CVSS analysis. In other words, the positive effect of PBL in managing and encouraging constructive conflict among construction engineering/management students could be detected, quantified, and analyzed in this work through CVSS.

### 3.1.2. Mentoring and Developing Others

The second competency in the Collaborate quadrant of CVSS that displayed significant improvement of post assessment over pre-assessment is Mentoring and Developing Others. Mentoring in classical terms can be defined as the relationship between a typically older, more experienced person and an inexperienced, typically younger person, where the mentor helps the mentee learn ways of navigating the world at work (Kram, 1985).

Recruitments in organizations may be made with different expectations: some recruits are expected to know basic theories related to the scope of work, while others are expected to have intricate experience in a specialized area (Quinn et al., 2014). This factor can be illustrated with an example from the construction industry. When a graduate construction professional is recruited into a firm, they will be expected to understand concepts such as plan reading, principles of estimating, and scheduling, while more experienced employees of the firm will help the recruit orient towards specific job responsibilities such as construction inspection and client relationships.

This process of providing help to the recruit to fulfill the overall goals of the organization will be termed "mentoring." In this case, the mentor-mentee relationship will be very important to the firm's future in maintaining client relations, ensuring quality construction, and bringing in more revenue, and this relationship depends solely upon the effectiveness of the transition of *knowledge* from the mentor to the mentee. However, if a position is being filled for a more specialized job position (e.g., project manager for a project), then the potential recruit will be expected to have years of experience in the specific field and even serve as a mentor to other members of the team. Researchers have identified mentoring abilities of employees as an important aspect of career development (Allen, 2003; Dreher & Ash, 1990), and attempts have also been made to understand the propensity to mentor others, and the relationship between prosocial personality characteristics and personal motives for mentoring others (Allen, 2003). Serving as a mentor was described as a key activity associated with the third stage of a four stage model of professional career development (Dalton et al., 1977), and this inclination to serve as a mentor has also been shown to depend on age (Allen et al., 1997).

Moreover, one's empathy (the ability to relate to the concerns of others) also influences one's inclination towards being a good mentor (Allen, 2003). In one study, greater psychological well-being was reported among more than half the study group due to natural mentoring relationships (Hurd & Zimmerman, 2014), and this psychological well-being among employees can potentially lead to greater developments of an organization's productivity

(Masalimova & Nigmatov, 2015). It is therefore important that graduates from construction programs possess the personality traits to become effective mentors, and incline toward the development of others. It has been shown in this PBL study, the overall inclination of the students towards mentoring and developing others was significantly improved.

## Control Quadrant

The results from this study have also shown significant improvements in the Control quadrant. Based on the paired *t* test results of the pre- and-post assessment of CVSS competencies, it is evident that PBL has caused a positive impact on those personality traits of students which are inclined toward maintaining stability and control in a work environment. These improvements will potentially help students organize and manage critical information, operations, and coordinate activities across multiple projects. These skills are expected from construction engineers and managers for effective functioning in the industry (Odusami, 2002).

### 3.2.1. Organizing Information Flows

Organizing Information Flows is one of two competencies showing significant improvement due to PBL in the Control quadrant. A huge amount of information is constantly produced in this era of digital technology, and it is estimated that in one year alone there is more data created than in all the books ever written and published (Quinn et al., 2014). As a result, there is a sudden, great need to manage this huge data overload. Effective employees are expected to screen useful information from the rest and there is a need to acquire data, organize it, and draw conclusions which can in turn be implemented to solve important problems within an organization.

From the perspective of a construction engineer or manager, one example of the need to organize information flow is when construction firms submit job bids. Employees are expected to create estimates based on quantity take off, find alternative materials and methods for serving the goals of the contract better, and to review designs. To take care of the above, one needs to collect information on existing construction techniques, find the cost of alternative materials, and consider environmental implications. This process requires one to collect information, organize it in a logical order and classification, and draw conclusions. Putting it into perspective, there are many small pieces of information that need to be collected and correlated to deliver a finished product. Therefore, it is important that construction professionals are equipped with skills for organizing information flow. Technical skills such as statistical analysis, scheduling, and estimating techniques may also play a key role in determining whether an individual is capable of managing and organizing information. While higher education stresses technical skillsets, the much-needed soft skills are sometimes lacking. PBL appears to address such areas related to people skills.

### 3.2.2. Planning and Coordinating Projects

Planning is one of the most essential elements in the smooth execution of a construction project. By its nature the construction industry requires engineers and managers to coordinate between different personnel who may belong to different departments, companies, agencies, and, in some cases, even countries. Several parties—contractors, sub-contractors, architect-engineers, and construction project managers—collaboratively work to fulfill the requirements of a construction project as required by the owner. The success of a construction project then depends upon the effective synchronization, alignment, and adjustment of contributions from the different parties involved (Bygballe et al., 2016). There are moreover different contractual relationships among these different parties that can complicate matters very quickly in case of disputes, if proper planning and coordinating is not done. The interdependent complexity of different parties involved in construction dictates specific methods of coordination (Bresnen, 1990), and much of the planning of tasks and delegating responsibilities to others and/or coordinating with other parties is dependent upon the people skills of those in construction and management. In this work, statistically significant improvements in the skills of the overall class to plan and coordinate projects have been observed (Table 2), and these improvements due to PBL could be effectively quantified by CVSS.

## Compete Quadrant

PBL has also improved the competence and productivity-oriented personality traits of the class. These competencies focus a person's ability to complete their activities on time and clarify the understanding of the goals and visions of an organization. Moreover, competent people have a better understanding of their environment and resources. Typically, they are also aware of any constraints that can lead to the failure of the organization's goals. This study shows enhancement in this section.

### 3.3.1. Designing and Organizing

Significant improvement has been observed for the competency identified as Designing and Organizing (Table 2). A critical skill expected by professionals is the ability to clearly set expectations from team members and then designing

and organizing the work accordingly (Quinn et al., 2014). This is an effort to ensure that overall productivity increases and this constant motivation of fellow team members may be achieved in part through the Plan, Do, Check, and Act (PDCA) cycle (Lincoln & Syed, 2011). Construction engineering and management students can often be trained in these technical aspects of productivity. However, the overall clarity of thought, instinctive understanding of surroundings, assessment of resources, and motivation of fellow employees through soft skills can be lost in an academic setting. The results of this study indicate that this can be instilled through PBL. The improvement of this competency among the students due to PBL has been quantified in this study through CVSS.

## Create Quadrant

The Create quadrant of the CVSS instrument represents competencies that cause individuals to adapt to changes in their surroundings, possibly through innovating new ways of accomplishing tasks. Because of the dynamic nature of the construction industry, construction engineers and managers should have competencies that enable them to overcome them and adapt. This study has proven that PBL can further induce innovation-oriented competencies in students.

### 3.4.1. Fueling and Fostering Innovation

In the construction field, innovation affects the potential for economic growth (Blayse & Manley, 2004). Innovation can be defined as a novel change and improvement in a process, product, or system (Bygballe & Ingemansson, 2014) and, in the construction industry, novel changes may result from modifying certain technical aspects of the processes or management strategies (Slaughter, 1998). To bring about innovative management techniques, some level of outside-the-box thinking will be required of the employee and this spirit of promoting innovative change can be applicable to clients, construction managers, and designers. However, alternative construction methods may not be commonly anticipated by contractors or sub-contractors, who may be obligated to follow a set of specifications mainly compiled by the architect-engineer, client, or construction manager. Therefore, fostering an attitude geared towards such innovative practices among construction engineering and management graduates is important. The results show significant improvement in Fueling and Fostering Innovation competency due to PBL.

## Conclusion

In this study, the Problem-Based Learning (PBL) technique was used in the capstone course CME 488 in the Construction Management and Construction Engineering program of North Dakota State University. The effects of PBL were assessed by the Competing Values Framework's (CVF) model and with the Competing Values Skill Surveys (CVSS). Out of the 20 competencies spread over four quadrants, significant improvements were observed for six competencies when compared between pre-assessment and post assessment scores. These improvements were statistically significant, as confirmed from paired *t* test (Table 2). The improvements in the six competencies were spread across two each in the Collaborate and Control quadrants, and one each in the Compete and Create quadrants of the CVSS instrument. This study has quantified the positive effects of PBL on the development of certain soft skills of students in the capstone course. The following are the specific conclusions from this study:

- Out of the twenty competencies, the students experienced significant improvements in six competencies. This improvement was assessed through self-assessment surveys administered before and after the semester's work involving problem-based learning (PBL)
- In the Collaborate quadrant, significant improvements were observed in two out of the five competencies. These were, Managing and Encouraging Constructive Conflict and Mentoring and Developing Others.
- Significant improvements in Managing and Encouraging Constructive Conflict competency signifies the ability of the subjects to effectively utilize professional differences of opinion among co-workers in a constructive manner to achieve the desired goals of the concerned project.
- Significant improvements in Mentoring and Developing Others competency indicates that the students can be better equipped to train, motivate, and empathize with junior co-workers and new recruits to ultimately influence retention capabilities of the concerned organization.
- In the Control quadrant, significant improvements were observed in two out of the five competencies. These were, Organizing Information Flows and Planning and Coordinating Projects.
- Significant improvements in Organizing Information Flows competency indicates PBL can help the students efficiently manage the flow of data and information, e.g., preparing bids, making schedules and estimates, projects control etc. in a logical order for successful completion of a construction project.
- Significant improvements in Planning and Coordinating Projects competency indicates PBL can help the students plan things in a logical and optimized order, multi-task between activities, and coordinate among personnel for successful implementation of a construction project.

- In the Compete quadrant, significant improvement was observed in Designing and Organizing competency.
- Significant improvement in the Designing and Organizing competency indicates that PBL can help the students organize tasks effectively. This can be achieved through overall clarity of thought, instinctive understanding of surroundings, assessment of resources, and motivation of fellow employees through soft skills.
- In the Create quadrant, significant improvement was observed in Fueling and Fostering Innovation competency.
- Fueling and Fostering Innovation competency drives the tendencies of a student to be involved in spearheading or participating and promoting in disruptive technologies which can improve the productivity of the construction process.
- One of the limitations of this approach is the long duration it takes to test a hypothesis.
- For future work, PBL can be used to teach other instructional and laboratory-based courses in engineering and other disciplines. Additionally, the impacts of this style of teaching can be assessed on technical skills specific to the discipline, in addition to soft skills.

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