Assessing the Capability and Maturity of Capstone Software Engineering Projects

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Abstract
This paper describes an approach for assessing the capability and maturity of undergraduate software engineering projects. The approach is based on a simple adaptation of the Capability Maturity Model ® Integration and a hybrid version of the Team Software Process (TSPi). The approach was evaluated using 6 capstone project teams comprising 23 undergraduate software engineering students. A capability and maturity baseline was established at the end of first semester. A second capability and maturity assessment was undertaken towards the end of second semester. The approach was shown to focus student attention on process improvement and on the attainment of realistic and measurable project management goals. The approach was also found to contribute to the development of teamwork and leadership skills, and to prepare students for professional practice.

Keywords: Capability Maturity Model, Process Improvement, Capstone Project

1 Introduction
This paper describes an approach for managing capstone projects for use by student software engineering teams. The approach has been adapted from the Capability Maturity Model ® Integration (CMMI ®) (Chrissis et al., 2003) and a hybrid version of the Team Software Process (TSPi) (Humphrey, 1999).

The goals of the approach are to:
• focus student attention on project management, process improvement, and risk management;
• develop leadership and teamwork skills in which students set and achieve measurable goals;
• encourage personal and team reflection in a manner consistent with professional best practice; and
• be of appropriate scope and complexity for use by undergraduate student teams.

2 Background
The Joint Task Force on Computing Curricula of the IEEE Computer Society and the Association for Computing Machinery (ACM) recommends that undergraduate computing degree programs include a senior capstone project, normally undertaken in the final year of study. Students are expected to apply skills attained throughout their degree program to a software development activity of significant scope, and to demonstrate adequate preparation for entry to professional practice in a computing discipline (IEEE/ACM 2001, p. 57, 75).

In addition to applying technical skills to a real-world problem, capstone projects enable students to broaden non-technical skills that are difficult to develop in a normal classroom setting. These can include leadership, teamwork, project management, and processes improvement skills.

2.1 Project Management
Delivering a large capstone project on-time and without exceeding effort expectations is a daunting task for many students. This is particularly true for students who have limited experience working on a project of significant scope as a member of a team. In these cases, tracking individual effort while managing project milestones, requirements and risks becomes particularly important.

In previous studies, time sheets have been used to track student effort associated with class time, personal study, and group work on software design and testing assignments (Carrington, 1998), to identify the effort associated with the various activities comprising a software engineering assignment (Blind et al., 2005), and in capstone projects (Clark, 2007).

The Personal Software Process (PSP) (Humphrey, 2000) provides a standard time sheet format that can be used to log the effort and size associated with individual activities. The resulting historical data can then be used to estimate how long similar activities will take when planning future project work.

The Team Software Process (TSPi) (Humphrey, 1999) incorporates the PSP, and can be used in team-based capstone projects (Hillburn and Humphrey, 2002). In the TSPi, each member of the project team is assigned a management role in addition to having technical responsibilities. The project management roles defined in the TSPi are Team Leader, Planning Manager,
Development Manager, Quality/Process Manager, and Support Manager. Each role has its own set of goals and responsibilities, with an extensive set of well-defined processes, forms, and workflow scripts.

However, experience with the relatively heavyweight TSPi has led some to the conclusion that a more agile approach is better suited to capstone projects (Umphress et al., 2002).

The authors' institution has adopted a hybrid approach in which students remain responsible for the goals of assigned TSPi project management roles (von Konsky and Robey, 2005). The initial hybrid approach has the following features.

- At the beginning of each semester, team members are assigned one of the project management roles defined in the TSPi. Students change roles between semesters.
- Each student is expected to achieve the goals associated with their assigned project management role, as outlined in the TSPi.
- Students are required to upload PSP logs to an online database on a weekly basis.
- Students are required to implement the subset of TSPi processes and practices associated with tracking the project status using an earned value approach. This is transparently done using the online database, which is visible to all stakeholders.
- Project managers may choose to adopt or adapt other TSPi processes as they see fit. If a student team successfully implements all of the TSPi processes and practices, then they are likely to attain all project management goals.
- Project managers may choose not to adopt or adapt the optional TSPi processes and practices, and are free to invent their own more flexible alternatives.
- Students implement the Goal Question Metric (GQM) process (Basili and Rombach, 1988) to identify and track metrics that demonstrate attainment of goals associated with their assigned project management role.
- At the end of each semester, students are required to demonstrate attainment of their project management goals during a poster session attended by project stakeholders, graduates, future capstone project students, industry partners, and academic staff.
- In addition to the poster, students are required to submit a conference format paper on technical outcomes, and an engineering journal. Other artefacts may also be submitted for formal assessment. An assessment agreement is negotiated with project teams, with the understanding that roughly half of the marks will be awarded for project management outcomes.

This approach requires students to quantitatively demonstrate attainment of TSPi project management goals, but introduces some degree of flexibility in how they do so.

While the initial approach was generally found to be successful, students tended to neglect process improvement and risk management. The approach has therefore been extended to overcome this limitation, and this is the principal contribution described in this paper.

2.2 Process Improvement

Approaches to Total Quality Management (TQM) monitor the effectiveness of development processes using metrics and other feedback, such that an organization can take action to improve those processes when goals are not being achieved (Weises et al. 2002)

The Software Engineering Institute (SEI) of Carnegie Mellon University has developed frameworks to address the quality management and process improvement needs of the software development community. These allow
software organizations to reflect on the maturity of their quality processes and identify areas for improvement. The ultimate goal is to evolve a mature quality culture within the organization, such that all processes are optimised based on objective metrics. SEI frameworks include staged and continuous forms of the CMMI.

The CMMI Staged Model is depicted in Figure 1. The model contains 5 levels that characterize the quality maturity of an organization. Each level defines Process Areas (PA), each with specific Goals and Key Practices. Each Process Area must be implemented for an organization to be considered at that level. All Process Areas associated with lower levels must also be implemented.

The CMMI Continuous Model is depicted in Figure 2. In this model, Process Areas are grouped into categories for Process Management, Project Management, Engineering, and Support, but the maturity level of each Process Area is independently assessed.

3 Capstone Project Capability and Maturity

A simplified version of the continuous CMMI model was adapted to characterise the capability and maturity of final year projects in software engineering.

3.1 Software Engineering Capstone Project

The approach was developed for a capstone project in software engineering at an Australian university. The project constitutes 50% of a full-time load in the final year of study. Students were each expected to devote 16 to 20 hours per week to the project for a total of 24 teaching weeks spanning two semesters.

In 2006, there were 23 students in 6 project teams. Each team worked on a different project, in conjunction with an industry partner. Teams met with an academic supervisor and the industry partner for one hour each week to review the project status.

A one-hour weekly seminar was conducted with all teams to discuss teamwork and leadership issues, effort and size estimation techniques, risk management, process improvement, and other related issues.

Each student was assigned a project management role in accordance with the hybrid TSPi (von Konsky and Robey, 2005). Attainment of project management goals was assessed during a poster session held at the end of each semester. The poster assessment was a formal component of the final mark.

Each team was required to undertake a minimum of three development iterations: one in first semester and two in second semester.

<table>
<thead>
<tr>
<th>Level</th>
<th>Name</th>
<th>Criteria</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>Not Performed (Initial)</td>
<td>One or more of the specific goals or practices is not satisfied.</td>
</tr>
<tr>
<td>2</td>
<td>Performed</td>
<td>The goals and practices associated with the Process Area are satisfied but processes are not formally documented.</td>
</tr>
<tr>
<td>3</td>
<td>Defined</td>
<td>The goals and practices associated with the Process Area are met and the processes are formally documented.</td>
</tr>
<tr>
<td>4</td>
<td>Managed</td>
<td>Statistical or other quantitative methods are used to support management decisions.</td>
</tr>
<tr>
<td>5</td>
<td>Optimised</td>
<td>Trends are analysed and processes are adapted to meet needs.</td>
</tr>
</tbody>
</table>

Table 1. Criteria for each Maturity Level

3.2 Maturity Levels

For each student project team, an academic staff member assessed the maturity level associated with each Process Area, using evidence supplied by the team. Goals and Key Practices associated with each Process Area were assessed against the criteria shown in Table 1 to determine the appropriate level.

This assessment was undertaken at the end of semester 1 to establish a baseline for each Process Area. The assessment was repeated towards the end of semester 2 in order to gauge the extent of any improvement.

Artefacts presented for capability and maturity assessment could include, but were not limited to:

- records associated with implemented processes, including those adopted or adapted from the TSPi or invented by the team;
- process models and workflow scripts, and evidence of their implementation;
- meeting minutes;
- engineering journals;
- data in the on-line project database;
3.3 Assessed Process Areas

The maturity levels of eleven Process Areas in four categories were assessed towards the end of each semester. In keeping with the CMMI, the four categories were: Process Management, Project Management, Engineering and Support.

Although twenty-two Process Areas are included in the SEI version of CMMI, only eleven are used in this exercise to focus attention on important areas and reduce the scope of assessment to one suitable for use in a classroom exercise.

A spreadsheet used to record evidence for a hypothetical project team during the assessment meeting is shown in Figure 3. For each Process Area, the spreadsheet records the evidence provided by the team, the location where processes are defined, and the responsible party. In the figure, evidence of a process improvement focus associated with PA 2 is found in Process Improvement Proposal (PIP) and Post Mortem forms, using processes defined in the TSPi book. Evidence of implementing processes leading to a quality product associated with Process Area 8 can be found in completed Code Inspection checklists, metrics reports, and test data using processes defined in the TSPi book and in a project binder.

While the TSPi textbook defines a code inspection process, other teams may have chosen to adopt an alternate inspection process and to formally document it in the project binder. To a certain extent, however, adopting processes in the textbook is easier since the processes have already been defined there.

Once entered on the spreadsheet, the levels for each Process Area were automatically plotted by the spreadsheet in the Chart worksheet (not shown) in a manner similar to that of Figure 2.

The Team Leader, Supervisor, and Industry Partner acknowledge the assessment outcome by signing at the bottom of a printed version of the form.

A description of each Process Category and its related Process Areas follows.

**Process Management Category**

The TSPi defines a post mortem process, normally conducted at the end of each development iteration. The TSPi also specifies a Process Improvement Proposal (PIP) form. Both of these are useful starting points for teams in developing and managing processes for the Process Management category.
Process Areas and associated Goals and Key Practices in the Process Management category are as follows:

**PA 1: Establish a process focus**
- Identify core processes
- Establish process performance baselines
- Implement processes

**PA 2: Establish a process improvement focus**
- Establish a process improvement focus
- Determine process improvement opportunities
- Select process improvements
- Define and deploy process improvements
- Measure process improvement

**Project Management Category**

Prior to the beginning of each development iteration, the Planning Manager is required to upload a Work Breakdown Structure (WBS) in a format similar to the TSpI TASK form. Each team member also uploads weekly PSP data. This information is automatically used to track the project status and is available on-line to all project stakeholders. A representative example showing data from two development iterations is shown in Figure 4. Planned Value (PV) is the planned effort, expressed as a percentage of the total plan. Earned Value (EV) is the percentage of the plan that has been completed. Actual Effort (AE) is also shown, and expressed as a percentage of the plan. Consequently, the actual effort can exceed 100% when it is greater than the planned effort at the end of the iteration. This can be seen in the data for the iteration plotted on the upper left-hand side of Figure 3.

Keeping data current in the on-line system is a project requirement, and satisfies many of the Key Practices associated with Process Areas 3 and 4. However, Process Area 3 includes the need to plan for acquiring needed knowledge and skills. Process Area 4 requires students to demonstrate that the team can manage corrective action to closure in those cases where the project is not progressing according to the plan. Evidence of implementing these practices is required to achieve Level 2 (Performed), and the process must also be documented to achieve Level 3 (Defined). For risk management, students must identify and analyse risks, and develop and implement mitigation plans. These topics are covered in a pre-requisite subject, but are also reviewed in class during the weekly capstone project seminar.

Process Areas and associated Goals and Key Practices in the Project Management category are as follows.

**PA 3: Develop a concise and accurate project plan**
- Estimate effort
- Establish schedule
- Plan for needed knowledge and skills
- Assign and allocate resources

**PA 4: Effectively monitor and manage project**
- Monitor project against plan
- Manage corrective action to closure

**PA 5: Effectively monitor and manage risks**
- Identify and analyse risks
- Develop risk mitigation plans
- Implement risk mitigation plans

**Engineering Category**
The Engineering Category requires teams to manage requirements and ensure their traceability. Implementations must be reviewed, well tested, and based on sound designs. Moreover, alternative design approaches must be considered and an appropriate one selected based on established criteria and constraints.

Process Areas in the Engineering Category are as follows:

**PA 6: Effectively manage requirements**
- Develop and validate product requirements
- Manage requirements change
- Manage requirements traceability
- Manage inconsistencies between project work and requirements

**PA 7: Produce a technically sound solution**
- Develop alternative approaches and selection criteria
- Perform make, buy, or reuse analysis
- Design the solution
- Implement the design

**PA 8: Produce a high quality product**
- Perform design review
- Perform code review
- Unit test individual work products
- Integration testing
- Manage corrective action to closure

Support Category
The Support Category contains Process Areas for managing code, process artefacts, and related data. This will generally require the implementation and documentation of processes related to the use and monitoring of data from Configuration Management Systems (CMS), metrics collection software, testing environments like Junit, and other similar tools. The University provides teams with the Concurrent Versions System (CVS) for configuration management and Resource Standards Metrics (RSM) for collecting source code metrics. Although no pre-defined process is mandated, the Support Category falls within the responsibility of the Quality/Process Manager, who will generally need to establish processes for using these tools as part of that project management role.

Process Areas in the Support category are as follows:

**PA 9: Effectively track assets**
- Establish configuration management baselines
- Track and control changes
- Establish repository integrity

**PA 10: Effectively manage process efficacy**
- Establish a process to collect and store process artefacts
- Transparently communicate non-compliance issues

**PA 11: Effectively manage development environment**
- Specify data collection and storage procedures
- Establish verification environment

• Communicate product quality status as needed

### 4 Results

Results of the maturity assessments for the six capstone teams from 2006 are shown in Figure 5. Team 2 showed no improvement between the two assessments, but the other five showed improvement for many Process Areas.

For Assessment 1, teams were generally at Level 1 (Not Performed) or Level 2 (Performed) for most Process Areas.

Assessment 1 was conducted during the first iteration in semester 1, when most teams were concentrating on requirements gathering and analysis, and project managers were becoming familiar with their assigned project management role. In cases where Process Areas were assessed at Level 2 (Performed), teams were able to produce evidence to substantiate that they were following de facto processes, but these processes were not documented or managed.

Assessment 2 occurred during the third development iteration at the end of semester 2. For this assessment, there was an increase in the number of Process Areas assessed at Level 2 (Performed) and Level 3 (Defined).

In the second assessment, Team 6 was able to show a well defined and managed process for managing effort and schedule, with particular emphasis on establishing the skills and knowledge of team members and their subsequent assignment to particular development tasks. Consequently, Team 6 was assessed at Level 4 (Managed) for Process Area 3 (Develop a concise and accurate project plan).

Teams 1, 2, and 6 were assessed at Level 3 (Documented) for Process Area 5 (Effectively monitor and manage risks). Team 4 was assessed at Level 2 (Performed) for this Process Area, while Teams 2 and 4 were assessed at Level 1 (Not Performed). To be assessed at either the Performed or Defined Level, teams needed to show that they had identified and managed risks. To be assessed at the Defined level, however, it was also required that the process for this was well documented.

Table 2 shows the minimum, maximum, and median maturity levels for each Process Area at the second assessment. The minimum, maximum, and median improvement between assessments is also shown.

For nine of the eleven Process Areas, half the teams were at the Performed Level (2) or higher by the time of the second assessment. Of these, teams demonstrated slightly higher levels of maturity with respect to monitoring risks and ensuring a high level of product quality.
Figure 5. Maturity Levels for each Process Area for each team, where levels are (1) Not Performed, (2) Performed, (3) Defined, (4) and Managed. No team achieved Optimised (5) for any Key Process Area.
Half the teams demonstrated an improvement by one or more maturity levels for six of the eleven process areas. These were for Process Areas associated with planning and monitoring the project status, risks, requirements, quality, and assets.

Over half of the teams were assessed at the Performed Level (2) or higher for Process Area 10, demonstrating practices for storing process artefacts and transparently communicating them to stakeholders. Similarly, half of the teams were able to demonstrate that they effectively established a process improvement focus. While half of the teams were assessed at the Performed level or higher for Process Areas 2 and 10, teams did not tend to demonstrate maturity improvement between semesters in these areas. The exception was Team 6, which showed improvement in all areas except Process Area 1, because they were not able to show a documented approach for establishing process baselines.

Similarly, half of the teams were at the Performed Level (2) or higher for Process Area 11, demonstrating that they were able to effectively manage their development environment. However, only two teams demonstrated improved maturity levels in that Process Area. The
exceptions were teams 4 and 6. Four of the six teams had the potential to advanced to the Defined Level (3), which would have been achieved if they had documented the de facto processes used to manage their development environment.

5 Discussion

Results from capability and maturity assessments provide an opportunity for feedback and reflection for both teaching staff and project students.

5.1 Feedback and Reflection for Staff

Capability and maturity assessments provide teaching staff and supervisors with a snapshot of the Process Areas that teams are implementing, documenting, and managing. This information can be used to guide the depth and breadth of topics requiring more extensive treatment in the seminar series, as well as during weekly team meetings with the academic supervisor.

For example, Teams 4 and 6 were assessed at Level 2 (Performed) for Process Area 10 (Effectively manage process efficacy). These two teams had de facto processes that were shown to be working, but were not formally documented. All other teams were assessed at Level 1 (Not Performed) for this Process Area. The associated Key Practices require teams to establish processes to collect and store process artefacts, and to transparently communicate non-compliance. As a result of past poor performance for this Process Area, additional class time is now devoted to these topics.

5.2 Feedback and Reflection for Students

Capability and maturity assessments provide project teams with an opportunity to reflect on the achievement of goals associated with their assigned project management roles, and to identify potential areas for improvement. The purpose is to provide feedback only. Assessment results are not directly related to a mark or grade. In a similar fashion, CMMI assessments in industry are intended for organisational reflection and process improvement, not marketing or self-promotion.

At the end of semester 1, students are encouraged to reflect on the attainment of goals associated with their project management role, and highlight those things that they would do differently next time as part of that reflection. In part, the capability and maturity assessment provides a framework to assist students with this reflection.

At the beginning of semester 2, an exercise is conducted in the classroom in which students review the capability and maturity assessment from Semester 1 and complete TSPi Process Improvement Proposal (PIP) forms in areas shown to require improvement.

Similarly, students are encouraged to consider capability and maturity assessments when conducting the TSPi Post Mortem process, recommended at the end of each development iteration.

Student project managers may also choose to highlight improvements during poster presentations at the end of semester 2, following the second capability and maturity assessment.

Poster presentations are a component of the final assessment for each student. A representative example of an end-of-year poster is shown in Figure 6, which was produced by a Planning Manager. Capability and maturity improvements are shown in the upper right hand corner of the poster. Risk management issues are shown in the middle right, and planning accuracy is discussed on the lower left-hand side.

The approach helps students to develop teamwork skills, given the intentional overlap of goals associated with project management roles. The capability and maturity assessments also contribute to developing these skills since they require the team to show that they have worked together to implement, document, and manage the Key Practices.

The approach also helps students to develop leadership skills, given the focus on the specific goals associated with assigned project management portfolios. Moreover, capability and maturity assessments provide an opportunity to reflect on the effectiveness of that leadership, and to identify potential areas for improvement.

5.3 Outcomes for Graduates and Industry

Graduates are encouraged to list their capstone project management roles on their curriculum vitae. They are also encouraged to assemble a portfolio to show prospective employers their ability to set and achieve realistic goals in a team-based project environment.

Anecdotal evidence suggests that industry partners consider graduates who have participated in the capstone project to be "job-ready", with a demonstrated ability to work in teams and a strong appreciation of the importance of project management and process improvement. It is not uncommon for project students to be hired by the industry partner who sponsored their capstone project.

6 Conclusion

Conducting capstone projects using the hybrid TSPi in conjunction with capability and maturity assessments leads students to take greater personal responsibility for setting and attaining realistic goals, for measuring goal attainment using objective metrics, and for reflecting on opportunities for personal growth and improvement.

Student capstone project teams generally demonstrated improvement in the Process Management, Project Management, and Engineering categories, and to some extent the Support category, based on multiple capability and maturity assessments conducted at the end of each semester.

Leadership and teamwork skills are emphasised in the approach, and are shown to contribute to the quality and timeliness of technical project outcomes.
Equally important, the approach has a significant process focus, and is based on processes, key practices, and models used for process improvement adapted from industry, including the Goal-Question-Metric Process and Capability Maturity Model Integration.

7 References


