THE ASSESSMENT OF ENGINEERING REASONING RECORDED IN STUDENT ENGINEERING DESIGN JOURNALS

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ABSTRACT

An engineer's journal, also known as a *logbook,* is a key document where the individual contributions to a project and the evolving design rationale are made explicit. The development of project-based learning at Ecole Polytechnique Montreal is an ideal setting for students to use an individual or project journal. In the 1st year design project, a strong emphasis is put on the information elements and structure that must be present in the student's journal. In the 2nd and 3rd year projects the journal's content builds on this structure. This paper focuses on methods used to assess the contents of a 4th year student's journal. In this assessment model, the evaluator grades the journal content and provides feedback to the individual students according to three key parameters, namely: content diversity, critical thinking demonstration and project management information. The critical thinking abilities are assessed by reading through the journal content using a predefined analysis grid. This grid contains 11 "Critical Thinking intellectual standards" reformulated as questions so students and evaluators alike can get a better understanding of how the criteria applies specifically to journals. The paper discusses how the implementation and assessment of journals provides a formalized assessment structure to an empirical engineering practice. Moreover, a number of unexpected outcomes from the journal assessment process are also reported, such as: the increase of reusable information, the identification of an individual's contributions to a project, the sparse use of sketches to solve complex spatial problems, etc. Finally, the authors conclude on new perspectives to increase the efficiency of the journal assessments along with new opportunities for collaboration and exchange of information in a project context through the use of electronic journals.

KEYWORDS

Critical thinking, designer's journal, engineering reasoning, professional skills

CONTEXT OF JOURNAL USE

In January 2004, Ecole Polytechnique Montreal launched a major reform program for all its engineering curricula. The Mechanical Engineering department adopted the CDIO (Conceive-Design-Implement-Operate) approach to foster the changes needed to prepare its future engineers for the realities that the industry of the 21st century is facing [1]. One of the important CDIO standards is to encourage project-based learning where students participate in active and experiential learning through real product development situations.

The Mechanical Engineering curriculum is articulated around four integrated learning projects, which constitute a cohesive chain of learning experiences [2]. A brief description of these four major design projects is provided in Table 1.

Table 1
The four integrated learning projects at Ecole Polytechnique Montreal

	Description
Year 1	▪ 1 semester cornerstone project: 3 case studies and design exercises ▪ Set in a controlled design solution space in time and scope
Year 2	▪ 1 semester cornerstone project, presented in the form of a design contest ▪ Work focussed on conceptual design and prototype building/testing
Year 3	▪ 1 semester cornerstone project ▪ Individual assignment submitted by local companies or research laboratories
Year 4	▪ Capstone project covering 2 semesters with industrial partners ▪ Teams of 20 students from Ecole Polytechnique, the School of Industrial Design, and the School of Business and Management. ▪ Work focuses on Integrated Product Team functions.

ENGINEERING JOURNAL TRAINING

In the first year engineering learning project, students are presented with an engineering journal writing guide. The guide presents different notebook contents from famous scientists but also from past students (Figure 1, Figure 2 and Figure 3).

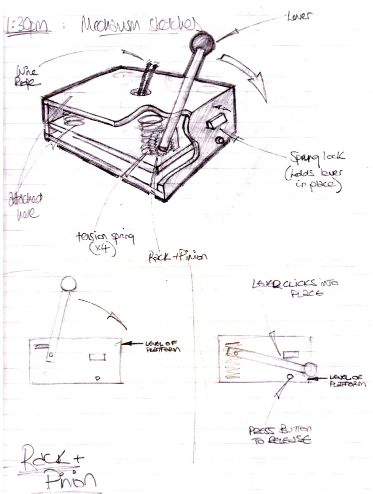

Figure 1 Journal sketches

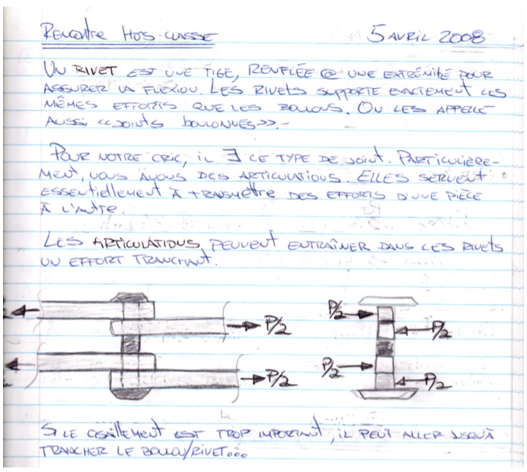

Figure 2 Journal calculations

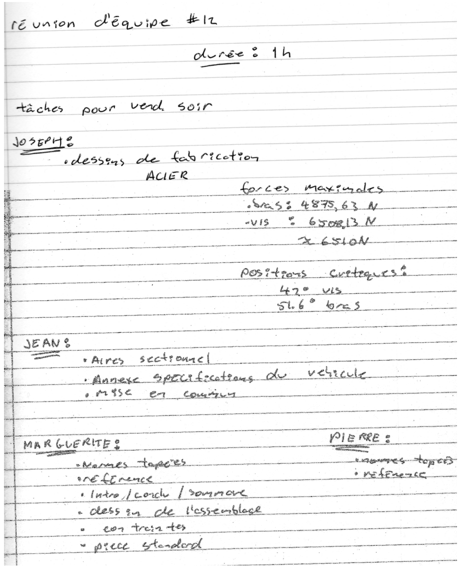

Figure 3 Journal meeting entry

The guide also defines the information expected to be found in an engineering journal detailing the structure and format it must adhere to as shown in Table 2. In this introduction to journals, the main goal is for students to become accustomed with the structure and the use of the journal more than to work on the actual journal technical content.

Table 2
Journal Tag types

Tag type	Why?	How?
Date and week number	Simplify navigation in the journal.	Clearly indicate the day's date and week number at the beginning of each entry in the journal.
Time spent	Conserve individual time sheet to be compiled by the team project management	Write down the time spent to complete each documented activity in the journal.
Page number	Ease information finding in the journal	Write down page numbers in each page corner in the journal (if not already printed).
External source reference	To conserve critical knowledge, identify where the information is with a brief summary for future project use.	Use standard reference formats as in scientific articles and books. File names, Internet hyperlink, consultation date, etc.
Meeting minutes	Conserve project team meeting conclusions, progress and justifications for decisions.	Note the location, date, time and complete with the meeting's subjects, decisions and actions.

This training is immediately followed by the active use by the students of journals in their integrated learning project. Students are closely followed by the teaching staff to assess if the journal structure respects the minimal information requirements defined in the journal writing guide.

ENGINEERING JOURNAL ASSESSMENT

Building on the first three years of journal writing and use, the 4th year project focuses more on the actual content of the journals than the information structure as illustrated in Figure 4.

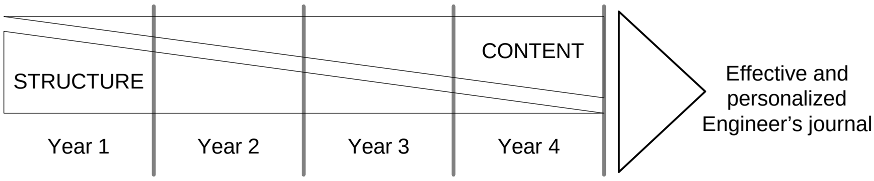

Figure 4 Focus of the journal assessment across the 4 year program [3]

In the 4th year project, the assessment of journals is part of the project grading system. During these capstone projects, students are asked for their journal on three occasions during the project. The teaching staff assesses the journal on the spot, grades and submits written comments. Only the final evaluation is kept on record for the grade awarded to the journal content. Students are hence given multiple opportunities to get feedback so they can correct their weaknesses in journal writing accordingly. The actual journal assessment process is in continuity with the previous training the students received.

Three main criteria are used to evaluate an engineering project journal:

- Variety of information types (*types of content*)
- Critical thinking demonstration (*critical thinking*)
- Project management information consignment (*project management information*)

Types of Content

The variety of information types in a journal is an indicator of the richness of approaches taken to solve problems. From an engineering journal content study [4, 5] the important information types were defined as shown in Table 3.

Table 3
Journal content types

Type	Class	Description
Textual	Hand written notes	Personal notes taken during individual or collaborative work.
	Meeting notes	Notes taken during a meeting.
	Contact details	Names, phone numbers, e-mail, addresses.
	Hand calculations	Simple or complex hand calculations used for evaluation of a situation.
	Tables and figures	Hand drawn or printed.
	Completed forms	Copy of official document.
Graphical	Sketch	Hand drawn, from pencil sketch to high quality rendering.
	Graphics and diagrams	Hand drawn
	CAD drawings	Printed and inserted in the journal.
Graphical and textual	External documents	Report sections, product information, pictures inserted in the journal.
	Annotated external documents	As above with manual notes added
	Annotated CAD drawings	Manual add-ons to existing drawings
	Memorandums	Post-it notes, highlighted notes, memory aids

The diversity of content is evaluated by paging through student journals and identifying occurrences for the different content families. More content types indicate that the student uses more ways to approach, document and solve difficult problems.

Critical thinking

The journal is also used as an open door to evaluate a student's problem solving processes. A properly used journal consigns in writing all problem solving steps, good or bad. This gives a unique insight to how students solve problems. To better use these observations the "Critical Thinking" approach to engineering reasoning was used to better structure the student problem resolution processes. In the Critical Thinking approach, 9 basic intellectual criteria are defined ([6] and Table 4). To be more specific to project work the questions were slightly reformulated and two other criteria were added, namely: Concision and Risk.

Table 4
Critical thinking in student Journals

Criteria	**Examples**
Clarity	Can you elaborate further? Can you give me an example? Can you illustrate what you mean?
Accuracy	How can we check this? How can we find if this is true? How can we verify or test this?
Precision	Can you be more specific? Can you give me more details? Can you be more exact?
Relevance	How is this linked to the problem? How does this weigh on the question? How does this help us to solve our problem?
Depth	What factors make this a difficult problem? What are the complexities of this question? What are the difficulties we must address?
Breadth	Do we need to look at this from another perspective? Must we consider another point of view? Should we look at this in other ways?
Logic	Does this make sense together? Is your first paragraph coherent with the last one? Do your conclusions come from the presented evidence?
Significance	Is this the most important problem to consider? Is this the central idea to focus on? Which of these facts is the most important?
Fairness	Do I have a personal interest in this problem? Do I support other's ideas too easily? Do I represent other's viewpoints sympathetically?
Concision	Is your message complete? What can you take out without losing the meaning?
Risk	What is the present risk level? Is this risk level acceptable? What could you do to reduce it?

The formulation of the criteria as questions in line with project work, gives students and the teaching staff a more pragmatic grasp of what the criteria mean in a project context. By reading through a student journal and using the intellectual criteria it becomes easier for the teacher and student to describe and discuss the strength and weaknesses of the contents of that specific journal.

Project management information

Journals must also document meeting tasks, responsibilities and decisions. Students from the previous 3 years of journal writing should have acquired these elements. The presence of the following critical items is evaluated without imposing on the students a journal template.

- Are there personal meeting minutes and notes present?
- Are individual tasks assigned to the student during meetings clearly identified in the journal?
- Are there written elements that show the student has worked on his assigned tasks?
- Is there a sufficient demonstration of progress over time towards completion of the tasks?
- Is there a compilation of all hours spent on the project?
- Are all entries to the journal dated?
- Are empty pages identified as intentionally left blank?
- Are there ripped out pages?

OUTCOMES

It is difficult to convince students that the use of journals in project work is essential. The starting point is to make journal writing a key component in a student's evaluation. Giving frequent feedback on the logbook content helps ligitimize the journal as a key engineering ool for students. But ultimately, it is while doing project work students truly understand the value of maintaining a journal.

Indeed, in a project-based learning context, students frequently retrieve older information that supported a decision that was not completely documented in reports but is needed later in the design process. They reuse other student's notes to continue their work when the project staffing is reorganized due to time constraints. They collaboratively sketch in each others journals during ideation and brainstorming. Reading the completed student journals at the end of the project by the teaching staff is a complete rerun of the project process flow; all decisions are in writing, good and bad. It is a great opportunity to better prepare the mentoring support provided by the teaching staff for the following projects.

Students appreciate feedback given through the journal. The written comments by the teaching staff become a starting point for constructive discussions about individual contributions to project work (ethics, responsibility, accountability, knowledge management, etc.).

FUTURE DEVELOPMENTS

In collaboration with the University of Bath (UK), where engineering logbooks have been the topic of extensive research over the past few years ([4], [5], [7]), a reflexive process will be proposed to the students next year. After they submit a report, they will be asked to go through their journal and tag the critical elements (Table 5) in their journal that were used to build the report. This exercise, illustrated in the example provided in Figure 5, highlights the link that exists between the ideas expressed in a journal and the final conclusions presented in a report. With this new approach, the journal will propose a richer context to evaluate the detailed process used to come to the conclusions that are published in the project reports.

Table 5
Journal content type proposed tags

Tag type (tag)	Description	Associated documents	Tag examples
Actions (A)	Tasks to be completed by a team member	Meeting notes	A, [E1_CR_21.doc]
Calculations (C)	Hand calculations	Report, Matlab, Excel	C, §(section), p(page) C, §A6, p73
Diagrams (D)	Hand drawn diagrams, org and flow charts, graphics, etc.	Report, Visio, Excel	D, §4.5, p18
Notes (N)	Personal notes	Report or meeting notes	N, §4.5, p18 N, [E1_CR_21.doc]
Sketches (S)	Sketch	Report	S, §2, p7 S, [part_name.prt]

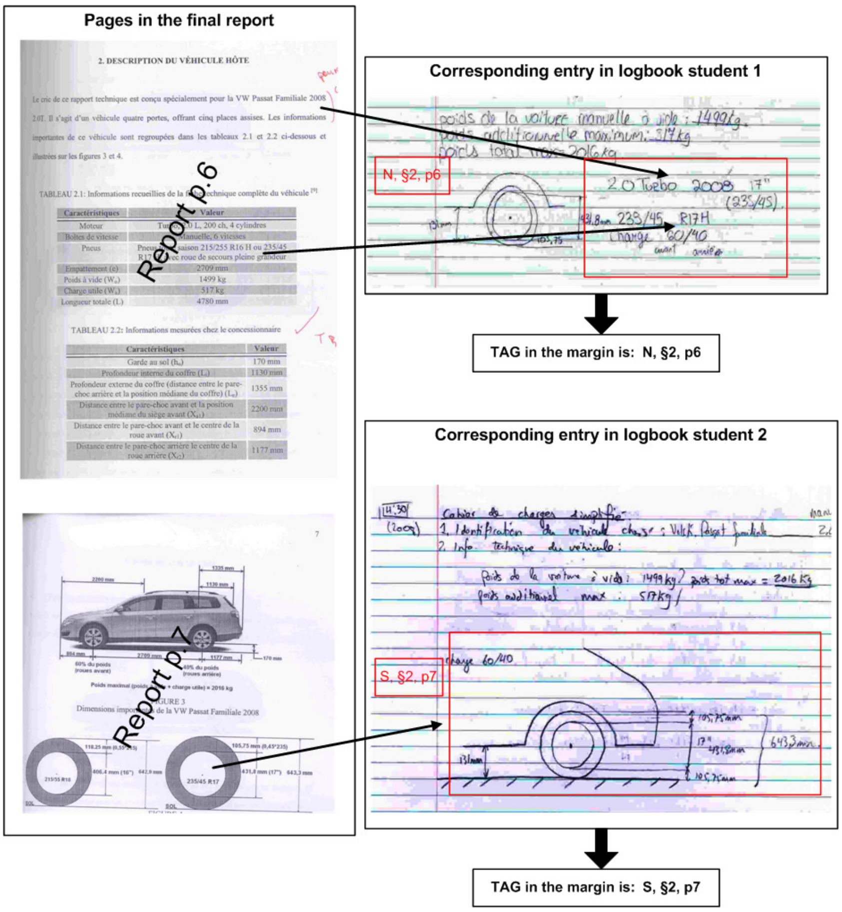

Figure 5 Journal tagging example

The paper based journal remains the most flexible support for project information [7]. Archiving journal information for rapid information retrieval remains a difficult mostly unsolved issue. Presently, no previous journal based team knowledge is passed on to future teams. This proposed tagging method is a first step in making paper based journals a searchable tool.

New tools (database, wikis, tablet PC's and Product Data Management) can enhance or even maybe replace paper based journals. A research project at École Polytechnique Montreal is currently underway to test the transition of information between three successive student teams working on a single project over three years without an actual face to face meeting between teams [8]. The present team is actively preparing the legacy information for the first transition in September 2009.

CONCLUSION

The proposed method to evaluate student engineering journals has helped the teaching staff to give structured feedback to students. High quality feedback promotes the use of journals and increases the amount of documented work done by students in project-based learning situations. Evaluating a properly written journal gives a unique view of the problem solving skills and difficulties students experience; this in turn helps the teaching staff to provide focused support to individuals or teams in need.

The theoretical teaching framework provided by the CDIO reform, the incubator environment for technology and teaching methodology integration at MATI Montreal, the close involvement of industry, and the multidisciplinary context in which the initiative has grown help support project-based learning. To further enhance the students' experience, the capstone projects now take place in a new state of the art 1000 m^2 Multimodal Learning Environment (MLE) [9].

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Biographical Information

Daniel Spooner is an engineer-in-residence at Ecole Polytechnique de Montreal (Canada). He also teaches at the University of Montreal's School of Industrial Design. In the last 15 years, he has lead development teams for more than 60 products in the transport, consumer, medical, and telecommunication industries. He also operates his own product design and engineering consulting firm involved in complex system design. He contributes actively to structure the CDIO capstone project initiative at Ecole Polytechnique.

Greg Huet is a research associate at Ecole Polytechnique de Montréal (Canada). He completed his PhD thesis in 2006 in the field of "design information and knowledge management". Greg is currently working on a number of research projects involving the use of new PLM tools to support collaborative engineering design activities. He is also one of the teachers/supervisors for the first year design project.

Clément Fortin is Professor at Ecole Polytechnique de Montréal (Canada) and the current Director of the Mechanical Engineering department. He was the Mechanical engineering program chair from 2004 until 2005 and has been involved in the CDIO initiative since 2004. His research interests include product and manufacturing process development, engineering change management, virtual environments for product development, and computer aided tolerancing.

Aurelian Vadean is assistant professor at Ecole Polytechnique de Montreal (Canada) in the Mechanical Engineering Department. He teaches the MEC4320 – Mechanical components analysis and optimization course, closely integrated to the capstone project course MEC4340 which he is one of the coordinators. He is also involved in developing protocols and products for the aeronautic industry and has a valuable experience in design and optimization through his numerous industrial contracts.

Rob Niewoehner is Director of Aeronautics at the US Naval Academy. Prior to joining the Naval Academy faculty, he served as a fleet F-14 pilot, and then as an experimental test pilot, including Chief Test Pilot for the F/A-18 E/F Super Hornet, throughout its development. His particular pedagogical interests include the promotion of Critical Thinking skills in engineering students.

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