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A Comprehensive Assessment Strategy for a PBL Environment

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***Abstract* – In this paper the authors report a comprehensive assessment strategy developed in consultation with industrial and academic participants for a problem based learning (PBL) course. Specifically, the strategy includes a set of assessment methodologies that are collectively employed to measure specific learning outcomes in a PBL environment. Applying this assessment strategy to a final year engineering course relating to the design of hybrid and electric vehicles it was found that we are able to instill a variety of technical and managerial skills in the undergraduate students.**

***Keywords* – Assessment in PBL, Higher Education, PBL Implementation, PBL Process and Student Engagement, Problem Based Learning.**

I. INTRODUCTION

Problem-based learning (PBL), pioneered at McMaster University's Medical school, is a pedagogical approach in which students master a subject by applying fundamental concepts to solve problems [1]. Thus, PBL facilitates the development of self-directed learning skills by working in groups through a structured problem solving strategy. Effectiveness of the problem based learning approach is disputed in the published literature. While some authors advocate for the superiority of the traditional teacher-centred approach based on direct guided instruction [2], [3], other suggest that student-centred inquiry based approaches like problem based learning [4]-[7] and teaching approaches with a strong experiential learning content [8], [9] encourage deep learning and provide superior learning outcomes. Nevertheless, with a successful application of this strategy to undergraduate and graduate life-long learners at McMaster University's medical school, PBL has now been adopted in several universities [10]-[13].

The underlying assumption in PBL is that learning is an active, integrated and constructive process that is influenced by social and contextual factors [10], [13]-[15]. Essentially, in PBL, students work in a group, wherein, after understanding the problem and identifying the current concepts that are applicable to solve the problem, they collectively work to evolve their knowledge and understanding to solve the problem in hand. Unlike the traditional forms of pedagogy where the material is delivered in a lecture-format, the role of an instructor is to mentor and advice the students, thereby playing a role of a facilitator. Thus, the defining characteristic of PBL is that it is a student-centric learning approach where the instructors play a role of facilitators.

To employ PBL in a classroom, an instructor must design good problems whose solution will adequately demonstrate that the learning objectives are met [16]. Such open-ended problems, referred to as ill-structured problems in PBL literature, tend to have multiple solutions. As a result, the students are expected to consider several possible solutions, evaluate the merits and demerits of each, and propose an optimal solution. Thus, these ill-structured problems serve as a stimulus for the students to identify the topics of interests to them and draw an outline of the way they want to study the topics. In doing so, the students take control of their education by defining their learning needs, planning classroom activity/discussions, and assessing their progress as well as that of their peers.

Besides this fundamental challenge of designing ill-structured problems, instructors must also device good evaluation techniques to assess whether students have met the overall learning objectives for the course [17], [18]. In doing so, it must be kept in mind that the assessment must be of the active learning process instead of the ability of the student to reproduce content from the memory [19]. As proposed by Reynolds,

It may be preferable, and more rigorous, for assessments to follow the PBL philosophy and to require the individual to analyse a problem, search for and then apply relevant information.

Gallagher [20] proposes that the assessment strategy in PBL should be such that it clearly evaluates the students' understanding of the problems and their solutions. Thus, assessment formats such as multiple choice, short-essay or long-essay questions will not be able to measure the extent to which the students' understanding of the subject has enhanced in the course of the problem-solving sessions.

In addition to the instructor's evaluation, students' inter-group and intra-group evaluations can also be a key component of the assessment. A noted by Bridges and Hallinger [13], self-evaluation of the students can be very valuable information for the students, and the instructor can also use this information to give a constructive feedback. Allen, Duch and Groh [21] integrated peer evaluation as a component of the overall grade of the students. In their peer evaluation process, the students evaluated other groups based on "attendance, degree of preparation for the class, listening and communication skills, ability to bring new and relevant information to the group, and ability to support and improve the functioning of the group".

Hmelo, Gotterer and Bransford [22] evaluated problem-solving processes as well as the resulting products in a PBL environment and compared the results with the traditional evaluation processes in a medical program. As part of their assessment, the authors evaluated the use of science concepts, strategy use, and self-directed learning. They found that such cognitive measures clearly able to distinguish the PBL students from their counterparts in

terms of knowledge, reasoning, and learning strategies. The authors concluded that such cognitive measures are important assessments in PBL.

Klegeris and Hurren [23] assessed student performance in a PBL course via a combination of peer evaluation as well as a midterm and final exam. Peer evaluation was done through an online evaluation tool and the students were judged based on the preparation, participation and the professionalism. They report that the students responded positively to the PBL environment and there was an improvement in student learning in this environment.

Belland, French and Ertmer [24] measured how three target outcomes in PBL were measured in 33 empirical studies and found that several of them were lacking in

"(a) theoretical frameworks for the assessed variables and constructs, (b) rationales for how chosen assessments matched the constructs measured or (c) other information required for readers to assess the validity of authors' interpretations."

In other words, the authors noted that many authors did not give sufficient information about how measures were (a) selected, (b) administered or (c) scored. The authors emphasize that reporting clearly on the selection, use, and psychometric properties of measures can lead to researchers realizing the shortcomings of measures and see the need to improve these measures for future use.

Considering the competencies that an engineer needs to develop and apply in professional practice, Lima, Mesquita, Fernandez, Marihno-Araujo and Tabelo [25] propose an assessment matrix that correlate the transversal competences that students are expected to develop within PBL context with a list of characteristics of the professional profile. By evaluating the matrix it is possible to identify if adequate assessment methods are used for the expected transversal competences.

From the literature it is clear that there is no single set of strategies that are suitable for all types of courses. With this in mind, in this work, we present the outcomes of a PBL approach employed in a fourth year undergraduate engineering technology course titled *Conceptual Design of Electric and Hybrid Electric Vehicles*. In section 2 we identify the research problem and define the goals of the study. In section 3 and the subsections therein, we present the details of the course structure, the delivery approach, and the course learning objectives. In section 4 we present the assessment methodology. In Section 5 we discuss the outcome of the assessment strategy. In section 6 we present the summary and conclusions from this work.

II. The Problem

The modern tools currently used in the automotive industry for designing, prototyping, testing, and manufacturing have significantly reduced the lead time to introduce a new vehicle into the market. Furthermore, most of the car manufacturers currently offer at least one electric or hybrid electric vehicle, and adopt new solutions every year to improve their existing designs. Preparing graduates for such a fast evolving industry is a difficult task because such a large content encompassing the past, present and potential future engineering solutions cannot be taught in a single course using a traditional lecture-intensive approach.

Keeping this in mind, to encourage students to master the art of self-learning to keep up with this rapidly evolving field, the students in this course are required to participate in many inquiry-based problem-solving activities. Specifically, in this course principles of PBL have been employed in which the students are required to use engineering design and analysis methods that have been taught in previous courses to perform a variety of problem-solving activities. In doing so, they are expected to search, identify and read relevant published research related to the design of modern vehicles, and are required to be aware of the current trends in the automotive industry. The goal of this study is to present the tools and methodologies used to assess the various activities that students are expected to perform within a PBL delivery approach.

III. Course Structure

The course described in this paper is *Conceptual Design of Electric and Hybrid Electric Vehicles*, and is delivered to full-time students enrolled in the last semester of an Automotive and Vehicle Technology program. As mentioned earlier, at this stage of their undergraduate university education, students have acquired considerable automotive engineering and management knowledge and gained relevant industrial experience through 12 months of full-time co-op employment. By employing the principles of PBL in conducting this course, the students use previously taught knowledge, investigate various forms of published information, use problem solving activities, identify relevant design approaches and distinguish between acceptable and non-acceptable solutions, and assess the applicability of innovative ideas. Thus, at the end of this course, the students have a good understanding of the state-of-the art in the field of automotive engineering. Further, the PBL approach also allows all students to carry out managerial and project management activities, to evaluate the information prepared by peers in formulating design solutions. Furthermore, the PBL approach provides the information needs to perform various forms of student assessment.

IV. Delivery Approach

The typical approach in PBL is to divide the course topics into weekly problems and to divide the class into groups. In the course described in this paper students are expected to cover eight problems, as presented by Centea and Srinivasan [26]. Each problem is divided into four major sections, each section containing multiple topics. The problems, the relevant sections and the suggested topics are presented by the instructor at the beginning of each week. Although students are expected to cover the topics suggested in every problem, each group is allowed to address a problem in its own way. Modern and

innovative approaches are encouraged as long as they are realistic and the groups can justify their solutions.

Right at the beginning of the term, the students are divided into groups of four. The approach used in selecting the groups plays an important role in both the weekly activities and the overall level of the designs. Allowing students to select the groups can provide some excellent projects. However, a potential pitfall is that weaker students could be working together in groups that provide much weaker/substandard designs. Besides, allowing students to work in groups based on friendship does not mimic the realities of the workplace. With these in mind, in this course, the students are grouped in an alphabetic order. This reduces the requests for group change to zero. Furthermore, students accept working with peers that might be academically stronger or weaker fully understanding that this approach mimics real workplace groups.

Every week one of the group members acts group manager. All four members of the group are expected to be involved in brainstorming activities in order to identify the knowledge already known, perform online inquiries using various forms of published information, recognize and study the latest level of knowledge in the subject area, use problem solving activities, and decide on the novel and innovative design approaches that will be employed in their design solutions. In this process, the manager is responsible for a variety of activities such as: moderating the brainstorming activities, dividing the work between group members, leading the face-to-face and online discussions, playing a lead role in the decision process, and setting deadlines for receiving the work from the other group members. Finally, the manager is required to prepare a written report and a presentation based on the materials submitted by the group members. Furthermore, the group manager is also required to submit a confidential assessment of the work done by each member of the group. We observed that by simulating such real life group environments students accept being led by peers who are academically stronger or weaker than themselves.

With eight problems and four-members per group, each student occupies the position of group manager twice and is a group member on six other occasions. It must be noted that the manager's deliverables depend on the work done by the other group members, and therefore a manager has to use his/her project management skills to ensure that the level of the received materials is of high standards. Meanwhile, the other three members are aware that their work is important for the weekly group deliverables. They tend to produce a good level of work as they will also expect to receive the same level of work when acting as group manager. This rotation of roles between manager and group member creates a sense of responsibility that increases both course attendance and student engagement.

In the PBL approach implemented in this course students learn in multiple ways. The initial weekly group brainstorming sessions address their general knowledge and encourage them to learn the topics and ideas presented by the group members. Students tackle each problem by performing inquiries, reading the concepts taught in several previous courses, and making connections between these knowledge concepts taught in these courses. One of the academic advantages of any capstone project is connecting the dots – a synthesis that can only be applied towards the end of the academic studies. Another opportunity to learn is during the weekly presentations when their design is scrutinized by the facilitator and the peer groups. These discussions promote self-reflection, active engagements via question-answer sessions among the students and have often been an opportunity to provide a constructive feedback.

V. Learning Objectives

The main objectives of the open-ended design course described in this paper include (i) recalling automotive engineering concepts learnt in previous courses; (ii) investigating modern comprehensive topics related to vehicle design; (iii) analysing design options and selecting appropriate solutions; (iv) delivering presentations, defending decisions, and debating; (v) developing group collaboration and managerial skills; (vi) preparing comprehensive reports that include technical, business and sustainability topics.

The achievement of the learning objectives have been analysed through course deliverables. As mentioned earlier, the course presented in this paper includes weekly group reports, weekly presentations, a final design presentation, and a final report. These deliverables, the weekly work done by the group members and the peer evaluations are assessed by different individuals. As discussed in the ensuing section, the assessment methods, as proposed by Graaff and Kolmos [27], have been employed so that they are compatible with these learning objectives.

VI. Assessment Methodology

Three major types of assessments have been used in evaluating student work, namely, individual assessments, group assessments, and peer evaluations. It must be noted that each assessment method has its own merits for a certain type of course deliverable. While a combination of these types of assessments can be employed for a particular set of deliverables, the choice of the proper assessment methodology is important to ensure that students' mastery of the learning objectives is appropriately measured.

Individual- and group-assessment are the most used evaluation methodologies by the course instructors. Group assessments reduce the amount of work done by the course instructor when compared with the individual assessment. However, individual assessments provide a better evaluation of the knowledge of individual students. Weaker students have an opportunity to hide their level of knowledge through group assessments, and therefore they prefer group assessment. On the other hand, students with high academic performances prefer individual assessments; they claim that group assessment downgrade

their performance. A study carried out at Alborg University by Komos and Holgaard [28] indicate that, overall, the majority of students prefer group assessments instead of individual assessments.

Peer assessments allow students to take responsibility for assessing other projects and for assessing one's contribution to the team efforts. Graaff and Bogaard [29] describe the distinction between peer assessments of *products* and *process performance*. In the *product peer assessment* students evaluate each other's product. In the *process performance peer assessment* students evaluate each other's performance as a member of the group.

In this course, all three assessment tools have been employed as each tool is more suitable than the others to measure the different learning objectives. The assessments are done by instructors (weekly report, presentation skills, assessment skills and final reports), by peers (content and presentation skills of the weekly presentations and individual contributions of group members) and by a panel of engineering managers for the automotive related industry (final presentations and final report).

Specifically, the following works from the students are assessed:

- Group assessments
  - Assessment of weekly reports
  - Assessment of the final report
  - External assessment
- Individual assessments
  - Assessment of presentation skills
  - Evaluation of the peer assessments
- Peer assessments
  - Peer assessments
  - Assessment of individual performance within a group

The following section elucidates these assessments in more detail.

VII. Assessment of Weekly and Final Reports

In this course, the students learn the material by solving eight problems. Each problem includes four themes, each of which focuses on several topics. The weekly work on a problem includes an analysis of the themes and topics, face-to-face and online brainstorming activities, individual work on a theme, as well as individual contributions to a weekly report. The role of the group manager is to moderate the brainstorming activities, divide the themes between group members, set deadlines, collect the written contributions of each group member, assemble these contributions into a report, submit the report, and finally, deliver a concise presentation of the themes and topics covered in the report.

The report is marked by the course facilitator based on its scientific content, the engineering solutions, the quality of justifications for the technical decisions, the level of complexity, as well as the level of creativity and innovation. In addition to these, the written communication skills and the overall aspect of the report are also assessed. The resulting mark for the weekly report is assigned to the group manager. Each member of the group will be assessed by multiplying this grade with weighting factor as described further in the paper.

The eight problems and the associated themes and topics are available to students at the beginning of the semester. While working on a problem they are required to identify the information that should be included in the week's report, keeping in mind that this cannot overlap with the expectations of a following week. Further, the amount of information that a group uses when preparing the report for any given problem is restricted to the information collected by the group members in that week. Also, students are encouraged to think of innovative solutions. As a consequence of these restrictions/ requirements, it is possible for a student to propose a design solution that is either too futuristic and impossible to be technically obtained within the suggested 3 to 5 years, or have a depth and breadth of knowledge below expectations. These issues are kept in a check via: (i) the feedback provided by the course facilitator for the weekly reports and (ii) the class questions and feedback provided at the end of each presentation.

Although a final report is a collection of weekly reports, the content of each chapter, generally representing one of the problems, incorporates the changes that are expected to be performed as a result of the feedback. Thus, the expectations for the final technical report, due at the end of the term, are higher than the expectations for the weekly reports. The final report is expected to have a uniform writing style, and must include an abstract, table of contents, list of figures, a detailed discussion section that covers the comprehensive design solution, and conclusions.

While writing the report for a problem, each group member is encouraged to contribute about three pages. By assembling these contributions and preparing a weekly report, a manager generally adds more information in order to prepare a consistent report and delivers a weekly document that usually ranges between 10 and 12 pages. When eight such reports are assembled, after addressing the suggested changes, a final report has usually more than 120 pages. The weight of a weekly report is 10% of a student's final grade, and the weight of the final report is 20% of the final grade. This high weight on the final report encourages students to incorporate all the changes suggested by the facilitator and their peers, and to put in additional efforts to ensure a best possible final report.

The final presentation of the project is delivered in front of a panel of judges, usually from the automotive-related industry and academia. In about four weeks after the final presentation, the students will have all the degree requirements fulfilled and will start looking for employment. Knowing this, the students generally try to impress these judges as they might be their future employers or graduate studies supervisors. Furthermore, students are proud of their final projects and make their own printed copies to include them in the portfolio that they will have with them at job interviews. Aware of all these facts, students generally put a lot of effort in preparing very good final report. As a consequence, the

assessment of the final report needs to be different than the assessment of a weekly report. Instead of assessing the technical and business component of the project that have already been assessed through the weekly reports, the assessment rubrics of the final report are aligned with the major learning outcomes of the course. Although this approach is often vague, the authors of this paper consider that this is an appropriate assessment approach for a capstone design course offered in the last semester of university education.

VIII. Assessment of Presentation Skills

Each week the group managers submit a written report, as described in the previous section, and deliver a presentation of the design solutions. Although the conceptual designs developed in this course include eight problems, presentations are delivered only for the first four. Thus, although a student acts as manager two times (for two problems) through the entire term, he/she will deliver only one presentation. A presentation is assessed based its content, the justification of the design solutions, the presentation skills, and the overall quality of the presentation.

It must be noted that in the earlier implementations of this course, students were required to prepare weekly presentations based on the number of groups and the timeframe assigned for these presentations. However, it was found that despite a restriction on presentation time, several students prepared slightly longer presentations – enough to put the later presenters in a disadvantage. To address this issue, corrective measures evolved over time. The first approach taken to eliminate this disadvantage was a weekly rotation of the order of presentations. The second approach was to provide a very strict timeframe for each presentation. This was accomplished using a *Pecha-Kucha* approach, that is now a norm in this course.

A *Pecha-Kucha 20x20 presentation*, as defined in Japan around 2003, includes 20 images, each of which are displayed for 20 seconds. The slides automatically change after 20 seconds, as a result of which the total length of the presentation is exactly 6 minutes and 40 seconds. Presenting a PowerPoint slide with technical content for only 20 seconds presents challenges. Each slide has to include only the relevant text and image that can be explained in 20 seconds. This requires a significant amount of thought, effort and preparation on the part of the presenter.

We observed that students participate in the Pecha-Kucha technical presentations with some initial reservation, feeling more confident about doing a Pecha-Kucha presentation. However, since each student presents only one problem during the term, they do not get the chance to prepare and deliver a second one. Further, the PBL course presented in this paper is offered in the last semester of four-year undergraduate education. As a result, the Pecha-Kutch approach cannot be repeated, and the learning outcome related to concise presentations is not completely achieved. To address this deficiency, the Pecha-Kucha approach is now employed for the technical presentations of a prerequisite course offered in the third year. It has been observed that students with an initial experience in the third year course, the Pecha-Kucha presentations in this course are well prepared and delivered.

IX. Peer Assessment of the Content and Presentations of Other Groups

While the course facilitator is responsible with assessing the content of the weekly reports and the presentation skills of each group manager, in order to increase students' engagement in the course and to allow them to critique their colleagues, a peer evaluation has been introduced in the course. In this, all students are asked to assess the technical content of the weekly presentations and the presentations skills of the group manager who delivers the presentation. To ensure that these peer evaluations are done in a fair and consistent way, students have been made aware that:

- a student is not allowed to assess his/her group
- the peer assessments of the presentations will not be included in the final grade of the presenter
- the peer assessments will be evaluated by the course facilitator and the corresponding marks will be included in the peer assessor's final mark

At the beginning of a presentation period all students receive an evaluation sheet (c.f. Table 1) specific for the weekly problem. Students use this sheet to assess the technical content of the presentation and the presentation skills of the presenter, rating the presenter on a numeric scale (either 1 to 5 or 1 to 10). As part of their evaluation activity, students provide numeric values for each the four themes and the four major elements of the presentation for the problem being assessed.

Table 1: Sample peer evaluation sheet.

Technical Content	A	B	C	D	E
Drivetrain					
Power Sources					
Vehicle control					
Power requirements					
Total					
Rank					
Presentation	A	B	C	D	E
Powerpoint					
Presentation skills					
Persuasive speech					
Reasons for solutions					
Total					
Rank					

Table 2: Sample peer evaluation summary sheet.

Name	**Rank Presentations**		
	Grp.	**Content**	**Presentation**
	A		
Your Grp.	B		
Problem #4	C		
Powertrain	D		
Date:	E		

In the sample peer evaluation sheet shown in Table 1, five groups (A to E) deliver their presentations within the 50 minutes of the class. Students are expected to assess only four groups as they are not allowed to evaluate their own group. After evaluating all the presentations, students calculate the total score of each group as they have recorded, and use this to rank the groups from 1 and 5. Their rankings of the groups for the technical content and the presentation are recorded on a peer evaluation summary sheet, as shown in Table 2.

After the first four problems have been assessed, the performance of the students as perceived by their peers is posted. In other words, these evaluations and rankings for the groups are posted. This enables the students to judge their relative performance in comparison to the other groups, encouraging the weaker group to put in additional efforts for the upcoming projects, while encouraging the groups performing well to keep the momentum.

As mentioned earlier, while all students enrolled in the course are peer assessed, these assessments are not included in their final grades, to avoid a conflict of interest. This approach has been seen in other courses. For instance, in Denmark, a country with a strong interest in the PBL approach, peer evaluation cannot be legally used in the calculation of the final grade, as reported by Moreira et al. [30]. In the PBL course presented in this paper the purpose of the peer assessment, is mostly to encourage students with low peer ranking to increase their efforts for the rest of the course. Students are aware that, at the end of the course, their conceptual designs will be judged by engineering managers from large automotive related companies. Thus, if their peers consider that their design projects are weak, the members of the groups with low ranking might expect similar evaluations from the external judges – a notion that encourage these students to increase their academic efforts in this course.

X. Evaluation of the Peer Assessments

To ensure high class attendance, good student involvement in all design projects presented in class and responsible peer assessments, the course instructor evaluates these assessments. The evaluation is included in the final grade of the peer assessor. A peer assessment lose marks if

- a peer assessment does not includes individual grades for all cells included in the evaluations sheet but provides a ranking
- all numeric grades are very high
- all the grades given to a group are the same
- no peer assessment has been submitted

The evaluation of a student's peer assessments represents 3% of the final course grade. Although this evaluation can be considered as participation marks, it significantly helps boost the class attendance which in most of the classes is 100%. A healthy class attendance promotes student involvement, often leading to technical debates/discussion on the design solutions. These class debates are encouraged as they often provide innovative design options for all the groups.

XI. Assessments of the Individual Performance Within a Group

It is often difficult to accurately assess the individual knowledge and performance of a student from his/her participation to a group project as the individual contribution cannot be verified. To address this issue, Lejk and Wyvill [31] proposed nine methods of assessing groups of students, one of them being the multiplication of the group mark by an individual weighting factor. A similar approach is proposed by Nepal [32] who suggests multiplying the group mark by an individual's contribution. Thus, peer evaluation can be used to assess an individual's contribution to the team work and to determine the weighting factor.

In the PBL implementation described in this paper, the weekly group work is managed by one member of the group. With eight problems and groups of 4 students each group members acts twice as group manager. One of the responsibilities of the group manager is to assess the contribution of each member of the group to the week's report. The manager learns to take this responsibility. Although this is a form of peer evaluation, the responsibilities of the manager are considered beyond the responsibilities of a regular peer evaluator and therefore can be assumed as being more accurate.

As mentioned earlier, the managers assess the contribution of the group members to the weekly work by evaluating their participation to brainstorming activities, their in-class face and online collaboration, and their contribution to the written report. These evaluations are provided by the managers as percentages given to each of the other three group members, which must add-up to 100%. The manager's evaluations are confidential. Each student's contribution is assessed by a group manager six times, and only the cumulative mark is provided to the student. The confidentiality is a premise for a fair peer assessment and gives managers the confidence that their assessment of the group members will not backfire against them when they will have the role of group members.

The percentage contribution provided by the group manager represents the weighting factor used to assess the individual performance within a group. If all three members of a group have the same contribution to a weekly report then each will receive an individual contribution of 33%. In this case, the weighting factor is 1. The weighting factor is capped at 1 if the contribution is greater than 33%. However, if the contribution is lower that 33%, the weighting factor is proportionately scaled.

It must be noted that the individual performance of a student within a group has a weight of 4% in the final course grade. This encourages students to perform and make significant contributions to the weekly reports, matching the efforts of the other group members.

XII. External Assessment of the Final Project

The external evaluation of the final project is a very important assessment of the course. One of the reasons is

the fact that this capstone project is a final product of a series of courses related to automotive engineering, electric and hybrid vehicles, engineering design, combined with business and management elements. Additionally, this assessment provides a *reality check* – a possible confrontation between innovative or futuristic design ideas and the solutions that can be realistically implemented in a 3 to 5 year timeframe.

The external assessment is performed by a panel of judges that includes engineering managers from major automotive related companies, and faculty members whose main research is related to electric and hybrid vehicles. Presenting their designs in front of possible future managers gives students an opportunity to showcase their accomplishments to relevant people in the industry, but at the same time also creates a certain level of anxiety as they expect to be questioned by knowledgeable people in this field. Being fully aware of this throughout the course, keeps the students motivated to prepare very good conceptual designs.

As part of the assessment, the external judges are provided score cards that allow them to assess (i) the level of technical knowledge in the fields covered in the course and (ii) the student skills in proposing an innovative business concept and describing a business model. Students need to convince the judges that the combination of technical solution and business model can be implemented in industry within 3 to 5 years. The judges, assuming the roles of automotive manufacturers, need to be able to convince rental vehicle service providers to buy their vehicles and use the suggested business model for profit.

The score cards contain areas where the judges provide detailed feedback on different aspects of the projects. The assessment topics specified in the score cards are related to the expected course learning outcomes. Thus, the score given by judges is an important measure of achievements of the learning outcomes.

XIII. Outcomes of the Assessment Strategy

The assessments used in this course are strongly correlated with its learning outcomes. At the end of the course, the students are expected to be able to *recall automotive engineering concepts learnt in previous courses* and to *investigate comprehensive topics related to vehicular design*. These two outcomes are fulfilled through weekly brainstorming and inquiry activities whose results are assessed through the weekly reports. Students are expected to be able to *analyse design options and select appropriate solutions*, an outcome assessed through weekly and final reports. The outcome of *delivering presentations, defending decisions and debating* is assessed through the weekly individual presentations and final group presentation in front of a panel of external judges. The *development of group collaboration and management skills* outcome is assessed through weekly and final reports, through peer evaluations, via the course facilitator's assessment of peer evaluations, and through manager's assessment of the individual performance within a group. The expected outcome of *preparing comprehensive reports that include technical, business and sustainability topics* is evaluated through the final project assessed separately by the course facilitator and by the external judges.

The combination of assessment approaches requires all students to be involved in inquiry, decision making, report writing , presenting and defending solutions, debating, working in groups both as members and managers, assessing their peers, accepting peer assessment and critique, and facing reality checks from industrial and academic judges who are completely unrelated to the course. This combination of weekly activities with an almost constant pace promotes deep learning in all students enrolled in the course. The PBL approach used in this capstone design course creates a learning environment that is correlated with students' deep learning, a fact also observed by Arana-Arexolaleiba and Zubizarreta [33]. This approach allows the development of all these activities, and permits the use of several assessment methods that address the course learning outcomes.

XIV. Summary and Conclusions

A PBL approach has been proposed in this course to allow for the development of a learning environment that encourages students to: (i) identify and read relevant published research related to the design of modern vehicles, (ii) enhance the awareness of the current trends in the automotive industry, (iii) use engineering design and analysis methods that have been taught in previous courses, (iv) undertake a variety of problem-solving activities, and in doing so (v) hone their technical, business-related, engineering collaborative and managerial skills.

An important goal of the course is to allow students to prepare open ended projects that include combining engineering solutions with a business model for an electric or hybrid electric vehicle that is feasible in 3 to 5 years for car rental or car-sharing purposes. Students are encouraged to include advanced but realistic solution that combine an innovative business model with modern technical specifications that have a minimal environmental impact and propose a vehicle design for a sustainable future.

Specifically, this study present the tools and methodologies used to assess the various activities that students are expected to perform within a PBL delivery approach that is implemented in the *Conceptual Design of Electric and Hybrid Electric Vehicles* course offered in the Faculty of Engineering at McMaster University. The paper presents the course structure, the course delivery and target learning approach, and also the assessment methodology along with the outcomes of the assessment strategy.

The assessment methodology, that is the main focus of this paper, is done in several forms, namely, individual assessments, group assessments and peer assessments. It has been found that each assessment addresses one or

more learning outcomes, and encourages students to perform inquiry, decision making, problem solving, project management, and managerial activities. Further, the set of assessment strategies correlated with the learning outcomes encourage deep learning or all students enrolled in the course.

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