IS A DEFINED COURSE PROJECT APPROPRIATE FOR ITS LEARNING OBJECTIVES? EBD APPROACH TO AN ENGINEERING DESIGN COURSE

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Abstract – Project-based learning is an inevitable part of current course curriculums, especially in engineering design courses. Incorporating course projects in curriculums is done for overcoming the lack of students’ familiarity with real-world challenges. Students either acquire or further develop those specific competencies upon successful completion of the course project. Thus, defining an appropriate course project becomes essential. The competencies that are fostered may depend either on the design problem or the project contexts. In this study, we employ an EBD approach to developing a framework for evaluating a course project regarding its fitness to course learning objectives. This framework makes it possible to elicit required competencies for accomplishing a course project and comparing it with the set of competencies in the course learning objectives. A case study of a flying house design project is presented to demonstrate the framework application. The discussion of the proposed framework and future directions to our research are presented at the end.

Keywords: Teaching Engineering Design, Teaching, Cognitive Competency, Project-Based Learning, Environment Based Design, Course Project, Course Learning Objectives, Task Analysis

1. INTRODUCTION

Nowadays incorporating course projects into design course is quite common since industries need educated engineers who are fostered further than solid engineering principles [1] and project-based learning is introduced to overcome the shortcoming of traditional teaching methods in this manner. In these course projects, students integrate knowing and doing [2] to learn knowledge and elements of the core curriculum, while developing their skills by applying them to real problems and producing artifacts. In the project-based learning, by transformations and construction of knowledge [3] Students obtain new understandings and new skills by coping with the project.

Learning outcomes for participants can be categorized into three categories of knowledge, skill-based and affective outcomes [4]. A set of related knowledge, skills, and attitude is called competencies [5]. Working on design projects can facilitate fostering various competencies in students [6], [7] which are essential for coping with the real-world problems in the industry environment. The participants’ cognitive competencies, namely a set of knowledge and skills which are fostered during the project term, are highly dependent on the project problem. Thus a critical concern arises which should not be overlooked: Is a defined course project fit for its learning objectives? In our study, we attempt to answer this question by evaluating the proposed course project compliance with learning objectives regarding involved cognitive competencies.

To answer this question the broad range of cognitive competencies that are engaged in performing design course project must be compared against the set of learning objectives. Developing the course objectives is beyond the scope of this study. Nonetheless studying cognitive competencies for the effective performing on a design task is ongoing research in the “Design Lab” at “Concordia University.” This research is fundamental to various applications such as designing a team for a task or designing a task for a team. In this paper, we approach the latter one, and we majorly discuss the suitability of a design course project.

In this paper, we employ environment analysis which is a part of the Environment Based Design (EBD) to decompose the problem explicitly. Following this analysis, we develop the criteria for evaluating course projects. This step frames the appropriate course project. We further develop a framework which makes the aspiration of
comparing the course project against the course learning objectives feasible and helps in identifying the mismatches between them. Further, we discuss approaches for reviewing the initially proposed project in such a way to fit the course learning objectives.

2. TASKS AND CONTEXTS IN A DESIGN PROJECT

Courses are taught for a reason, to accommodate a set of learning objectives. The learning objectives is a set of knowledge, skills and attitudes which can be referred as cognitive, psychomotor and affective domain competencies respectively according to Bloom’s taxonomy [8]. Project-based learning is pretty popular in the current education ecosystem as it is capable of challenging students with complex problems similar to real-world problems to equip them with specific competencies. Developing correct competencies can empower students in a way to match better with what industry looks for in the job market.

Currently, many instructors incorporate course projects in their courses especially the design courses which we focus on in our study. Design problems are commonly complex and open-ended, so they require a variety of competencies to be accomplished. Thus Students who have accomplished that project hold those competencies. This project-based learning approach can help students in improving a broader set of knowledge and skills rather than lecture-based learning. Performing creative task like design is associated with the mental stress. Mental stress [9] is defined by the real workload and performer’s mental capacity which consist of cognitive elements such as knowledge and affective elements such as feelings, forming the set of competencies. Our focus in this study is on the cognitive competencies, namely knowledge and skills. A significant concern which should be considered is to find out which competencies are required to be developed according to the learning objectives and which are developed by the proposed course project assigned to students. Defining a project according to the learning objectives becomes essential in this manner.

Different kinds of competencies are engaged to be developed during a design project. The first category of those competencies includes the task-specific [10] competencies which are associated with the design problem. This category consists of the technical knowledge and skills which are required to accomplish that specific design problem. The second category includes the competencies which are not associated with the tasks but with the context, that is the project. Delivering a product with specific qualities within a limited time by using available resources results in project accomplishment and is also independent of the design task. Thus for accomplishing the project in this context a set of task generic [10] competencies is required beside the task-specific competencies. Since Design projects are commonly interdisciplinary and complex, they are commonly done in a team setting. This context will engage teamwork and interpersonal competencies as well.

When a student performs well on a project, then he has related competencies to some extent. Students can develop specific competencies by accomplishing a specific course project. Specific competencies are fostered in participating students whether they had them before or acquired them through design session. If a student works on a project in an individual setting, this development can happen either from experience gained from performing project tasks or acquiring knowledge by studying independently from project performance. The complex projects are common to be performed in a group setting. In the team settings sharing knowledge and skills within the team might also be the case which leads to this development. In the team settings not always all team members perform the same task but they are assigned different tasks based on different principles. Independent from how tasks are distributed and assigned, in the integration and review phase of the project, knowledge and skills are transferred to some extent by interpersonal interactions such as communication and collaboration [11], [12].

A course project can be set up in various ways. So far, we provided various characteristics for a proposed course project whether in task specifications or context. Based on these characteristics different competencies are involved in the project accomplishment and so learning outcomes. In the next section, we attempt to provide a framework for evaluating a proposed course project against the presented criteria.

3. DEVELOPING EVALUATION CRITERIA FOR COURSE PROJECTS

We are interested in evaluating a proposed design problem as a course project for an engineering design course in which participants develop specific competencies. Commonly design problems are complex, so to evaluate the design problem we need to decompose and analyze this problem. Using a design methodology can be effective for this purpose. We employ the EBD approach toward analyzing the problem carefully and preparing it for
Major steps in an EBD driven design solution are as followed [13]. Environment analysis is the first step which is responsible for formulating the design problem systematically. This analysis includes a set of methods that are used for identifying and clarifying the concepts and their relations in a design problem. This analysis can lead us to elicit requirements of the design solution. After the environment analysis, conflict identification and solution generation are followed to provide a product description which is compatible with the environment. Using EBD to analyze the proposed course project and introducing the framework to evaluate it is discussed in this part; further, the steps of this framework are presented along with a graphical representation.

The instructor intends to evaluate if a defined course project is appropriate for the learning objectives, so she must start with an initial project statement. One design project consists of many related tasks toward developing a new product. To find out those competencies which are required for accomplishing the project, firstly, project tasks must be clearly defined. All essential underlying tasks must be completed to accomplish a project. So before going any further, we need to clarify what are those underlying tasks. A systematic method for eliciting requirements [14] is available within EBD methodology. This method is based on the environment analysis step of the EBD process. The instructor can use this method, that is based on a question/answering approach, to decompose the project statement into smaller work units.

Availability of relevant resources to perform a job is a part of its requirements for accomplishment. Since we are evaluating a course project, competencies which are required to its accomplishment are analogous to a subset of product requirements. The aforementioned question asking strategy can be employed for systematic analysis of small work units regarding required competencies for accomplishment. Taking this approach for generating questions can make a systematic review of tasks feasible. For answering the question of “how a small work unit can be performed” broad range of available techniques in the literature [15] that are available for cognitive task analysis can be practiced. These skills can answer the question and make it feasible to elicit required cognitive competencies as the sets of required skills and required knowledge for performing the task.

After understanding the design problem clearly, the instructor must compare the initial problem statement against the learning objectives. This comparison must be made according to competencies in the learning objectives set and competencies which are required for accomplishing the project. After this comparison, some modifications might be needed to change the open-ended design problem to fit the project definition of learning objectives. A step by step definition of the framework is presented in the following section to demonstrate the application of EBD approach in this evaluation.

4. THE FRAMEWORK FOR EVALUATING COURSE PROJECT – AN EBD APPROACH

According to the discussion which is presented earlier, the evaluation process for the course project definition starts from an initial problem statement and goes through comparison of the statement against the appropriate course project criteria. The outcome of this process is an evaluation of the proposed course project regarding meeting its learning objectives. In this section, we are providing the steps to follow for this process as a framework as well as a graphical presentation.

Recursive Object Modeling (ROM) [16] is used in the Environment Based Design (EBD) methodology for formal representation of the design problem. This step is before all other steps. So we start analyzing the problem by this representation.

Step 1: ROM representation of project statement and developing course expected outcomes

There are two independent tasks to be done at first step:

1-1 Formally present the initial problem statement by using Recursive Object Model (ROM) [16] for modelling the statement.

1-2 Develop learning objectives for the course regarding competencies that are intended to foster in participating students. In this step consider different categories of the competencies as discussed earlier. These categories include competencies specific to the design problem (task-specific) and competencies that depends on the project context (task generic) such as project management or interpersonal competencies essential for those projects which are done in a team setting.

Step 2: Decomposing project statement into small tasks

Follow the question asking approach which is introduced. This strategy includes generating questions from ROM
Step 3: Specifying required competencies for performing tasks

Ask how to perform underlying tasks. Start with tasks which are not dependent on other tasks and once they are defined, ask about the tasks that are depending on the defined tasks. Ask questions about methods of conducting identified underlying tasks of the problem. Project workload is decomposed into smaller work units. A set of questions mainly concerned about methods to be practiced for task accomplishment is generated. Different approaches become handy for answering these questions; The formal way can be cognitive task analysis, however, using other techniques for simple tasks might be useful as well. This analysis can also be done by instructor’s experience since the tasks can be detailed enough in the previous step. Answering those questions specifies the required cognitive competencies such as required knowledge or skill for each work unit.

Step 4: Comparing required and expected competencies

So far, we have developed two distinct sets of competencies regarding knowledge and skills. Compare the list of competencies which are required for the project accomplishment against the competencies that are intended to foster. For each competency, the result of this comparison can have a few combinations. Possible combinations of this comparison are presented in “Table 1”. Make the comparison of all competencies which are available in either of two lists. Roughly speaking, this step is analogous to conflicts identification step in EBD methodology which can be elaborated and followed by the solution generation step in further studies. Following this strategy, instructors acquire insights on the fitness of their proposed course project to learning objectives.

### Table 1: Possible cases of comparison for each competency

<table>
<thead>
<tr>
<th>Requisite in the learning objectives</th>
<th>Requisite for project accomplishment?</th>
<th>Project Evaluation result</th>
</tr>
</thead>
<tbody>
<tr>
<td>Required</td>
<td>Required</td>
<td>Problem complies with learning objectives</td>
</tr>
<tr>
<td>Required</td>
<td>Not Required</td>
<td>The problem is limited</td>
</tr>
<tr>
<td>Not Required</td>
<td>Required</td>
<td>Problem has inessential workloads</td>
</tr>
<tr>
<td>Not Required</td>
<td>Not Required</td>
<td>Problem complies with learning objectives</td>
</tr>
<tr>
<td>Non-mandatory</td>
<td>Required</td>
<td>Decision required</td>
</tr>
<tr>
<td>Non-mandatory</td>
<td>Not Required</td>
<td>Decision required</td>
</tr>
</tbody>
</table>

This framework enables the instructor to review the proposed course project regarding its fitness to learning objectives. Furthermore, this can provide insight on the opportunities for wise modifications of the course project.

Step 5: Reviewing the proposed problem statement

The design problem is an open-ended problem. The design problem can be limited by defining constraints or expanded by defining additional requirements. The evaluation results can be used for modifications of the initial design problem to make it more appropriate for the learning objectives. The instructor who is designing the course project must make decisions for limiting or expanding the problem definition to aspire to a more appropriate course project. By modifying the design problem according to the presented strategies, the instructor can present a precise definition of what is required for students to be done as a project and what should be avoided.

“Figure 1” shows a graphical representation of above-discussed framework. Interactions of the instructor with the framework are demonstrated as well as the flow of data objects.
5. CASE STUDY: AN ENGINEERING DESIGN COURSE

In this section, we provide a case study of a design project which is supposed to be implemented in an engineering design course. The steps which are introduced in the previous section are demonstrated in this section for this case. In our case study the initial project statement is:

“Design a flying house which can fly from one location to another location.”

Step 1: Create a ROM diagram

The ROM diagram based on the initial project statement is shown in “Figure 2”.

Questions are generated according to available templates as below:

- **Generic questions:**
  - What is a location?
  - What kind of location is in the design problem?
  - What is “fly”?
  - How to fly?
  - What is a house?

- **Domain questions:**
  - What is the lifecycle of the flying house?

These questions are provided with answers, and afterwards, they are integrated into the initial problem statement. This process is continued until particular tasks are available that can be analyzed regarding required competencies for accomplishment. In our case the clarified problem statement would be as follow:

“Design a building in which one family lives. The building can move through the air under control from one location to another location. Location can be air, sea or land.”

Step 3: Specifying required competencies for performing tasks

The underlying tasks of the project can be extracted from the clarified statement of the problem. These tasks and their relative set of knowledge and skills that are required for accomplishing them are presented in “Table 2”.

In this case study, we are demonstrating the process, and we are not scrutinizing tasks despite its feasibility. The
Step 4: Comparing required and expected competencies

As mentioned earlier, developing course learning objectives is not within the scope of this paper, but based on a presumed set of learning objectives, as the evaluation criteria, consider the following comparison in “Table 3”.

Step 5: Reviewing the problem statement

For the row #1 and #2, no modification is suggested since the competencies are required in both sets.

For the row #3, knowledge and skills of the telecommunication engineering must be involved in the course project as of instructor expectations whereas it is not necessary for accomplishing the proposed project statement. This insight enables the instructor to expand the problem statement wisely. The following requirement is suggested to be added to the design problem: “The house must be able to communicate with control towers on the ground.”

For comparison row #4 a decision must be made in which the instructor decides about the learning objectives. The instructor decides to avoid naval mechanic engineering as a learning objective, so the evaluation result is as row #4’.

For the row #4’ and #5 problem includes inessential workloads. We can consider constraining problem for a more appropriate course project. For this reason, we must get rid of underlying tasks that require specific competencies in #4 and #5. The following constraint is an effective example in dealing with this case: “The house must fly only between lands on the earth’s surface.”

This review helped us to modify the proposed course project in a way which makes it more appropriate for the course learning objectives. These modifications can be proposed according to instructor’s experience and wisely in the presence of the insights from the evaluation in step 4. We believe the application of the EBD’s next steps is effective for these modifications and we are interested in studying that in further research.

By employing the proposed framework in this case study, we demonstrated its effectiveness in the evaluation of the
course project and providing insights for its improvement toward a more appropriate course project. The updated problem statement is presented below:

- “Design a building in which one family lives. The building can move through the air under control from one location to another location.”
- “The house must be able to communicate with control towers on the ground.”
- “The house is required to fly only between lands on the earth’s surface.”

These statements can be integrated and represented as followed:

“Design a building in which one family lives. The building can move through the air under control from an area on the earth’s surface to another area on the earth’s surface. The building must communicate with control towers on the ground.”

A ROM representation of the final project statement is shown in “Figure 3”.

6. DISCUSSION AND CONCLUSION

In the present paper, a framework is developed to help instructors evaluate their course projects in such a way that complies with the learning objectives of their course. This framework is based on the fact that specific competencies are required to be present for the accomplishment of a project and working on such a project can foster those specific engaged competencies. Following the presented process the course instructor would be able to define a project in which students foster expected outcome competencies upon project accomplishment.

Even in the lecture-based teaching in which an instructor gives lectures on intended topics, learning those topics by students is not guaranteed. This guarantee does not come along with any teaching method since many parameters are influencing this matter. The fostering of expected specific competencies relies on accomplishing the project or at least performing the tasks which engage those competencies. In projects which are conducted in team settings, not everyone is doing all the tasks, so they are not equally involved in the project but sharing the knowledge, especially in integration phase of the design, can make this knowledge development happen for individuals.

Development of learning objectives is subject to performing well on associated tasks. For this purpose firstly student should not ignore the task and secondly the supervision role of the instructor should not be overlooked. Especially in design courses with a broad range of problems, it is possible for students to get lost regarding directing their project on a right path, so it seems active supervising of the instructor seems effective in fostering competencies in those projects. However, validating this statement needs more research.

This study cannot answer if course projects are successful in meeting their missions. The effectiveness of this teaching method is another concern that is broadly studied in the literature. Holding a specific competency is not a binary proposition, and it is subject to different levels of development. However, there are relevant studies in the literature which can be considered for integration while the assessment of competencies is a must before being able to measure the effectiveness. The assessment of competencies is another planned project in the design lab which can facilitate the measurement process of effectiveness.

This study takes a significant step toward designing an appropriate course project from scratch, but there are some limitations in this study that obstructs us to present an integrated framework for this design. We will continue this study in our future research. Since the design of the mentioned framework can be considered as a design problem, we are interested in a thorough application of next EBD steps, namely conflict identification and solution generation. This application can be integrated with the proposed framework in this study for a comprehensive framework for designing course projects. The present paper is considered as a study that attempts to design a task for a group of people for a specific set of learning outcomes. This study can be applied to the human resource practices for training and development in organizations. Another framework is under development to design a team for performing effective design.
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