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# Effectiveness of Sustainability in Engineering Education: Research Methods

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## 1 INTRODUCTION

The motivation of this research is to comprehend the changes in transforming engineering education, in particular to provide the next generation of engineers with sustainability attributes and competencies. The change includes integrating education about sustainability into existing engineering education, introducing a field of disciplines that specializes in sustainability and establishing engineering research on sustainability [1].

At the early phase of this research, two models for integrating sustainability in engineering education were identified. The models, the stand-alone and the integrated models, were presented as strategies in introducing of sustainability courses. Later, the attributes of the models were further developed considering findings and outcomes throughout the research processes. Sustainability courses in engineering education can be conceptually characterized in three dimensions comprises models, approaches and orientations [2]. The questions are however, which models, approaches and orientations that are effective in integrating sustainability in engineering education, and how the effectiveness of sustainability in engineering education is measured. In this paper, the researchers propose an overall research method to address the main research question and other research questions.

## 2 RESEARCH METHODOLOGY

The main expected outcome of the research is to design a framework that will integrate sustainability in engineering curricula. Subsequently, the framework will provides course developers with important elements to integrate sustainability in designing a course. Furthermore, the framework offers course developers structured design procedures and

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inspires developers to improve their teaching methods. To achieve the research outcomes, several real experiences and effective courses will be evaluated and analyzed, and the results then will be presented as the design procedures and exemplary teaching methods.

A mixed methods design was employed to obtain data from a group of course developers, teachers and students. A part of this study, qualitative data are viable in addressing research problems in which interview transcripts and observation reflections can ascertain the process of developing the courses. Document analyses also are very helpful in providing important inputs. In the other part of this study, quantitative data are feasible to address research problems such as to determine the effectiveness of the courses. The combination of qualitative and quantitative data provides a thorough understanding in addressing the research questions below, in particular to provide complementary qualitative data if quantitative data are inadequate [3].

## 2.1 Research questions

The main research question for this study is *What are the characteristic of effective course design for integrating sustainability in engineering education?* This overall research question was further defined with other two subsequent research questions (i and ii) and three background questions (iii to v).

- i) To what extent the structure of stand-alone course effective for integrating sustainability in engineering education?
- ii) To what extent the structure of integrated course effective for integrating sustainability in engineering education?
- iii) To what extent teaching methods can effectively integrate sustainability on both course structures?
- iv) To what extent principles of sustainability can effectively integrate on both course structure?
- v) To what extent competencies of sustainability can effectively integrate on both course structure?

## 3 RESEARCH DESIGN

### 3.1 Research model

Fig. 1 shows a research model which has been developed for this research. The research model was developed by adapting the basic cycle of design, investigate-plan-develop-evaluate, and will be used as overall research model. The cycle of the research model consists of four phases which includes qualitative and quantitative research methods. For phase one, the framework for course design was developed by reviewing sustainability courses across continents and collecting real practice feedbacks from experts and practitioners in sustainability. Outcomes from the phase one will serve as a base in developing instruments for the next phase. Two of the phases, phase two and phase three, will be focused on developing the framework for course design. Two case studies will be conducted at the phase two. It is expected that the in-depth case studies research will be able to point out the potential variables used to develop evaluation tools and indicator as well as to redesign the framework.

The phase three represents non-experimental research approaches. In this phase, effectiveness of five selected sustainability courses will be evaluated and indicated. Three types of evaluation tools to evaluate the effectiveness of sustainability courses were identified. The evaluation tools will use numerical values for evaluating the students' learning outcomes in term of knowledge, skills and attitudes. This non-experimental approach intended to evaluate the offered sustainability course without intervention on existing course design. Therefore, the



real practices can be justified and can serve as a point of departure to construct effective frameworks of course design.

The final phase is set in place to conduct validity tests on the proposed frameworks of course design. The proposed frameworks are used to develop an effective sustainability for both types of course structure. Two groups of course designers were assigned for the tests. The outcomes of the tests are feedbacks on the framework design.

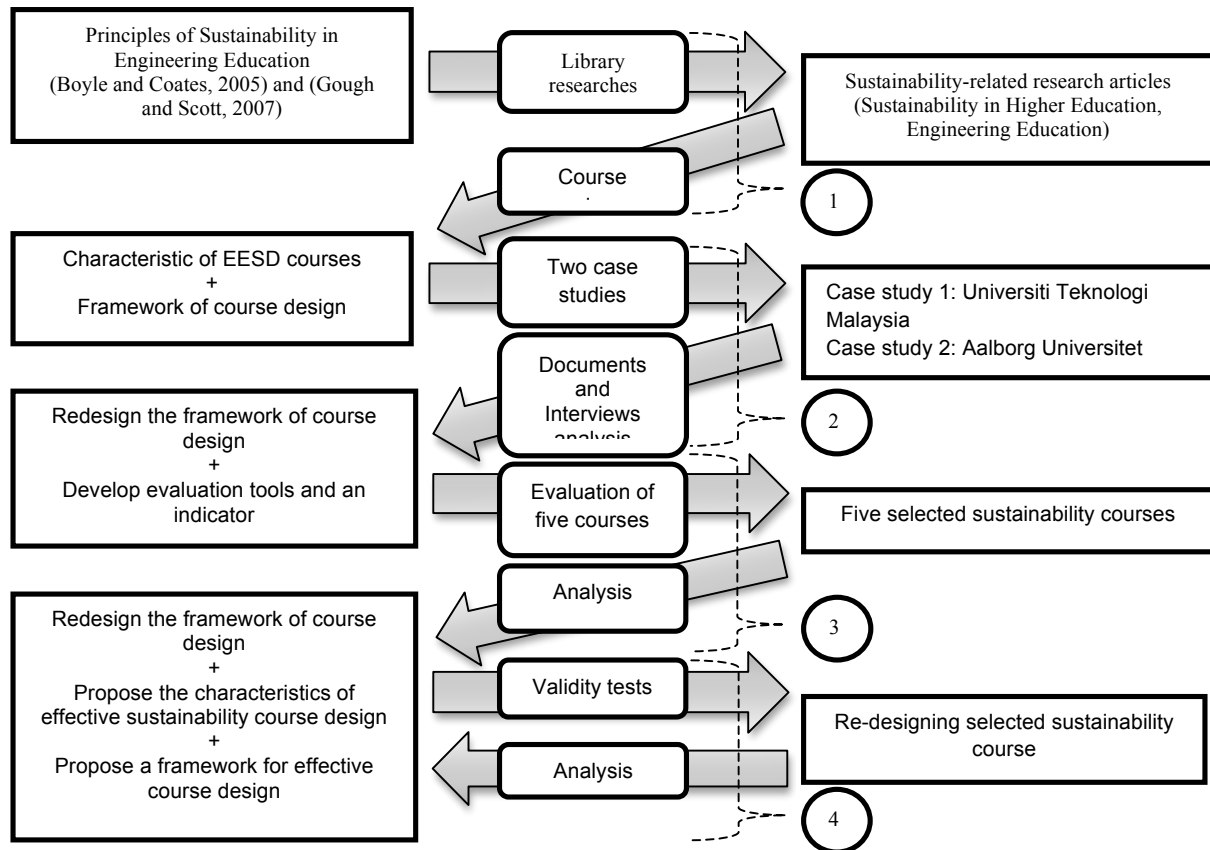


Fig. 1. Overall research model

### 3.2 Phase One: Exploring real world practices

This exploratory mixed methods design aims to get an overview of sustainability in engineering education and practical point of views on how experienced higher institution integrating sustainability in engineering curricula. Qualitative data were collected from accessible data bases and the data were analysed thematically. In this process, two set of concepts regarding sustainability in engineering education were developed and both concepts were translated to research instruments for testing. The research instruments were designed into two shapes, one as a ranking task (quantitative approach) and another one as a reflecting task (qualitative approach). The ranking task instrument was designed to identify sustainability experts' stance on concepts of sustainability in engineering education, whereas the reflecting task was designed to understand experts' justification on the concepts of sustainability in engineering education. The participated experts divided into three groups, two groups were from Universiti Teknologi Malaysia, Malaysia and Aalborg Universitet, Denmark, and another group was experts from various countries such as The Netherland, India, Spain and Switzerland. The experts' background are also varies in engineering disciplines. Fig. 2 depicts the exploratory mixed methods design that used to address research problem (iv) and executed in the phase one of overall research model. The outcomes from the



phase one provides preliminary knowledge and perspectives based on ten elements of learning about sustainability in engineering education. Later in phase four, the outcomes will rationalize the framework for designing sustainability course.

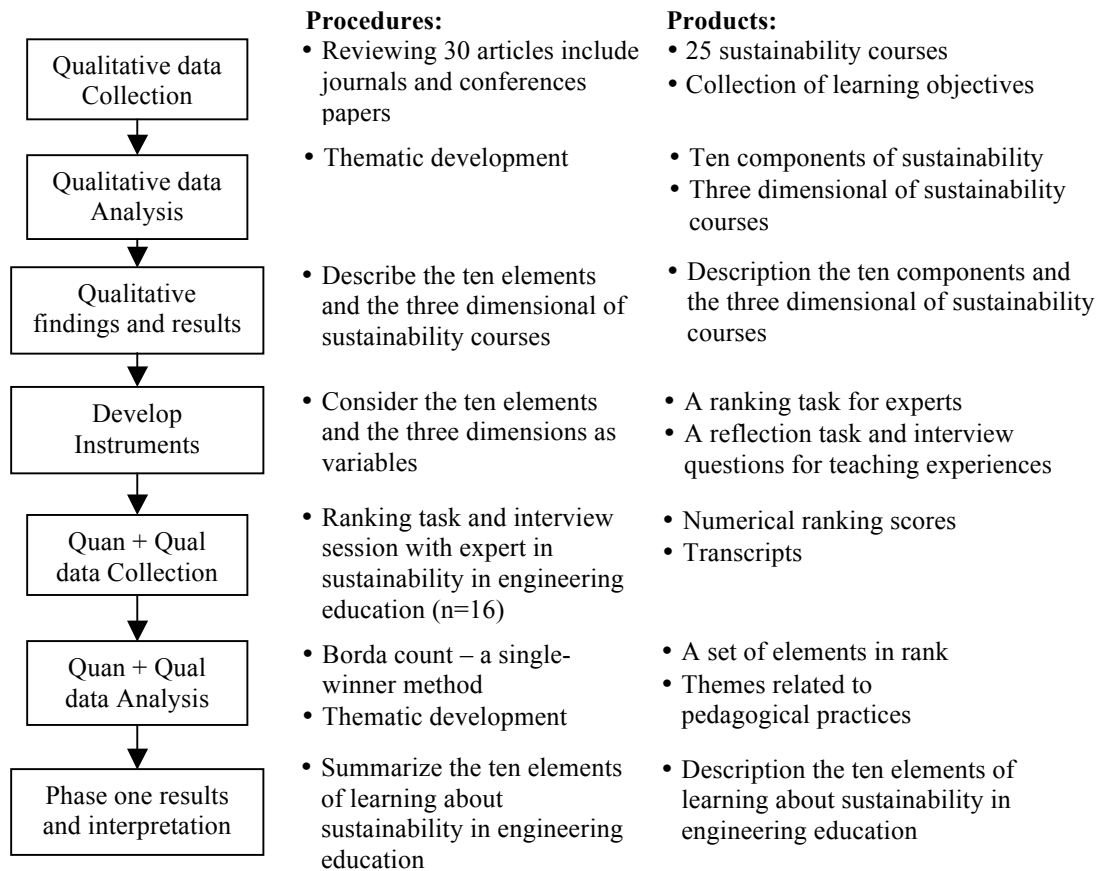


Fig. 2. Phase one - mixed methods design

### 3.3 Phase two: Excerpting positive practices

In the second phase, this study is using a qualitative approach in addressing research problems iii, iv and v. The study divided into two cases, the first case study was at Universiti Teknologi Malaysia and the second case will be at Aalborg Universitet. Both cases were selected to represent a wide range of engineering programs and sustainability courses, a variety of pedagogical strategies and the results from both cases will complementing to one and another. The qualitative data began with reviewing engineering programs offered at both universities either in undergraduate programs or postgraduate programs. Results from extensive qualitative data analyses and participation agreements from the Universiti Teknologi Malaysia, seven sustainability courses were met a point to be further study in-depth. In order to have a smooth session of collecting data, preparation of the research instruments are important and made upfront agreements with prospective university including every level of organisation, Dean of school, Head of Department, Course Coordinator and teachers. Fig. 3 shows qualitative research design in the phase two.

#### 3.3.1 Data collection process

The first case study was endured for three months which commenced from 20<sup>th</sup> February 2012 until 19<sup>th</sup> May 2012. The collections of data started off by inventorying the programs offered in Universiti Teknologi Malaysia. Eight programs were identified as having characteristics of sustainability. This was validated by course coordinators through feedback on a course inventory. Fig. 4 depicts the qualitative data collection process.

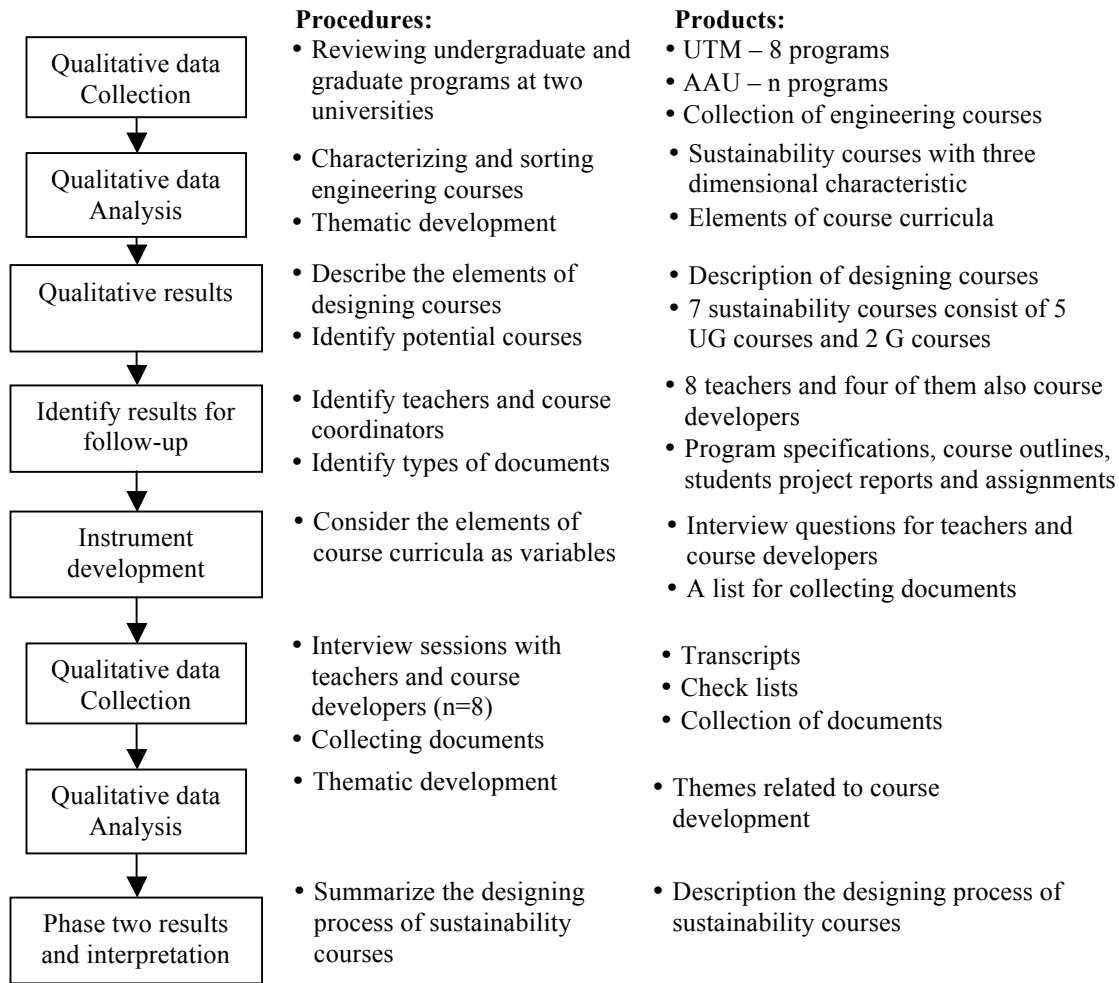


Fig. 3. Phase two – qualitative design

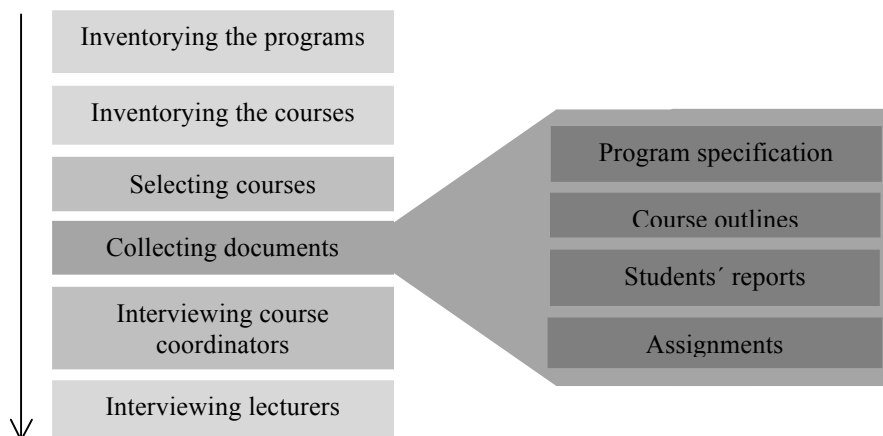


Fig. 4. Qualitative data collection process

Each of the selected courses were studied in-depth in term of the course development strategies, teachers' experiences of teaching sustainability in engineering education and students' understandings of learning sustainability. As the first steps of in-depth study, document analyses were administered to collect course outlines, students' reports and assignments. The strategies of course development in the perspectives of educational



philosophy and from pragmatic point of views were also clarified during the interview sessions with course coordinators.

The following Fig. 5 shows the research model of the case studies, demonstrating from the left to the right, the alignment of three components consisting of research variables, data collection techniques and expected research outcomes. The upper part of the research model shows how the research lead to the development of framework for designing sustainability courses while the lower part shows how the study will develop evaluation tools and indicator for sustainability in engineering education.

A study on the teaching and learning of sustainability in engineering education has provided reliable information and trusted data. Teachers and course coordinators were two groups of experts that were deemed as essential to understand the strategy of curricula design undertaken by universities. For instances, qualitative data such as teachers' experiences on teaching sustainability courses and course coordinators' design experiences are highly significant to the study. In pragmatic perspective, these data also provide important elements for developing main structures of the design framework of sustainability courses.

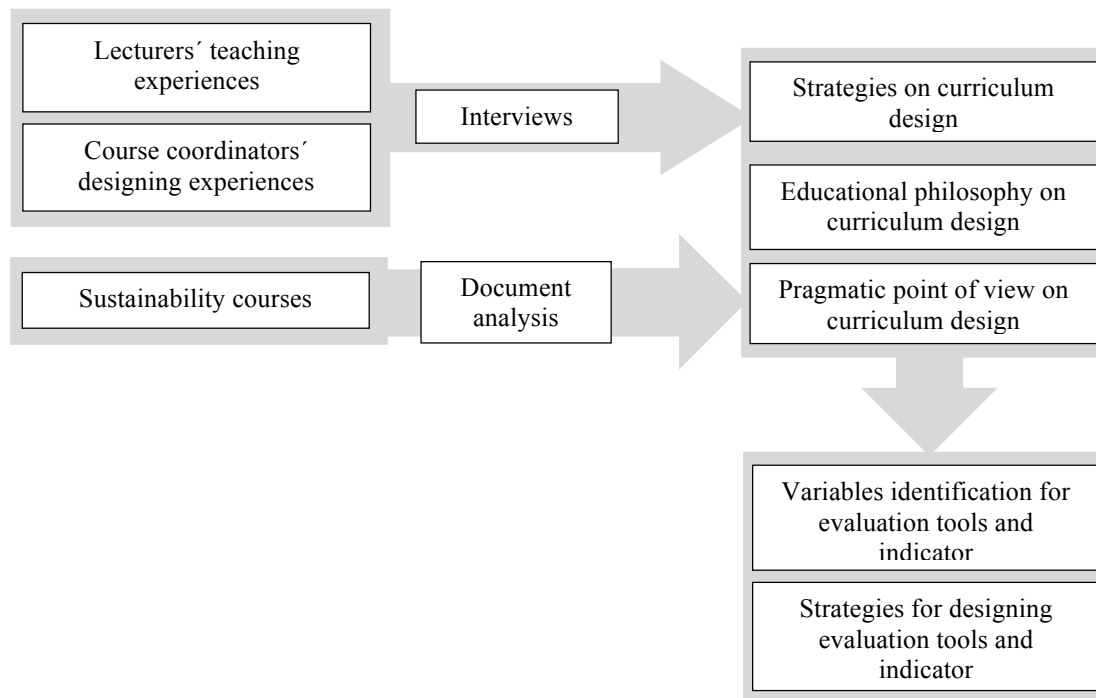


Fig. 5. Research model for case studies

### 3.4 Phase three: Evaluating course effectiveness

In a basic design cycle, evaluation is the final process that sort out the effectiveness and the ineffective of the design. Basically there are two approaches of evaluation, a product evaluation and a process evaluation. In a curriculum design, formative and summative evaluations are possible form of evaluations can be applied for evaluating the curriculum. Evaluating the course effectiveness requires indicator to determine the effectiveness of a sustainability course. The indicator has to be developed based on concepts and principles of sustainability.

In this study, effectiveness of the sustainability courses is defines as the capability to provide a sufficient requirement for achieving targets or goals outlined in the curricula. In practice, the targets or goals of the course can be identified by the learning objectives outline by the course developer. Therefore, as illustrate in Fig. 6, the capability of the course to provide the



sufficient requirement can be measured by evaluating the students learning outcomes and comparing it to the learning objectives. For this purpose, researcher has categorized students' learning outcomes into three elements, knowledge, skills and attitudes.

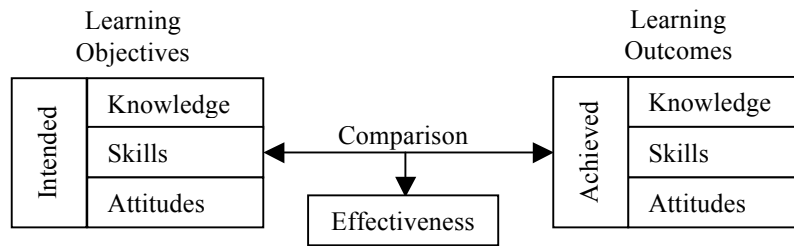


Fig. 6. Strategy of evaluating courses effectiveness

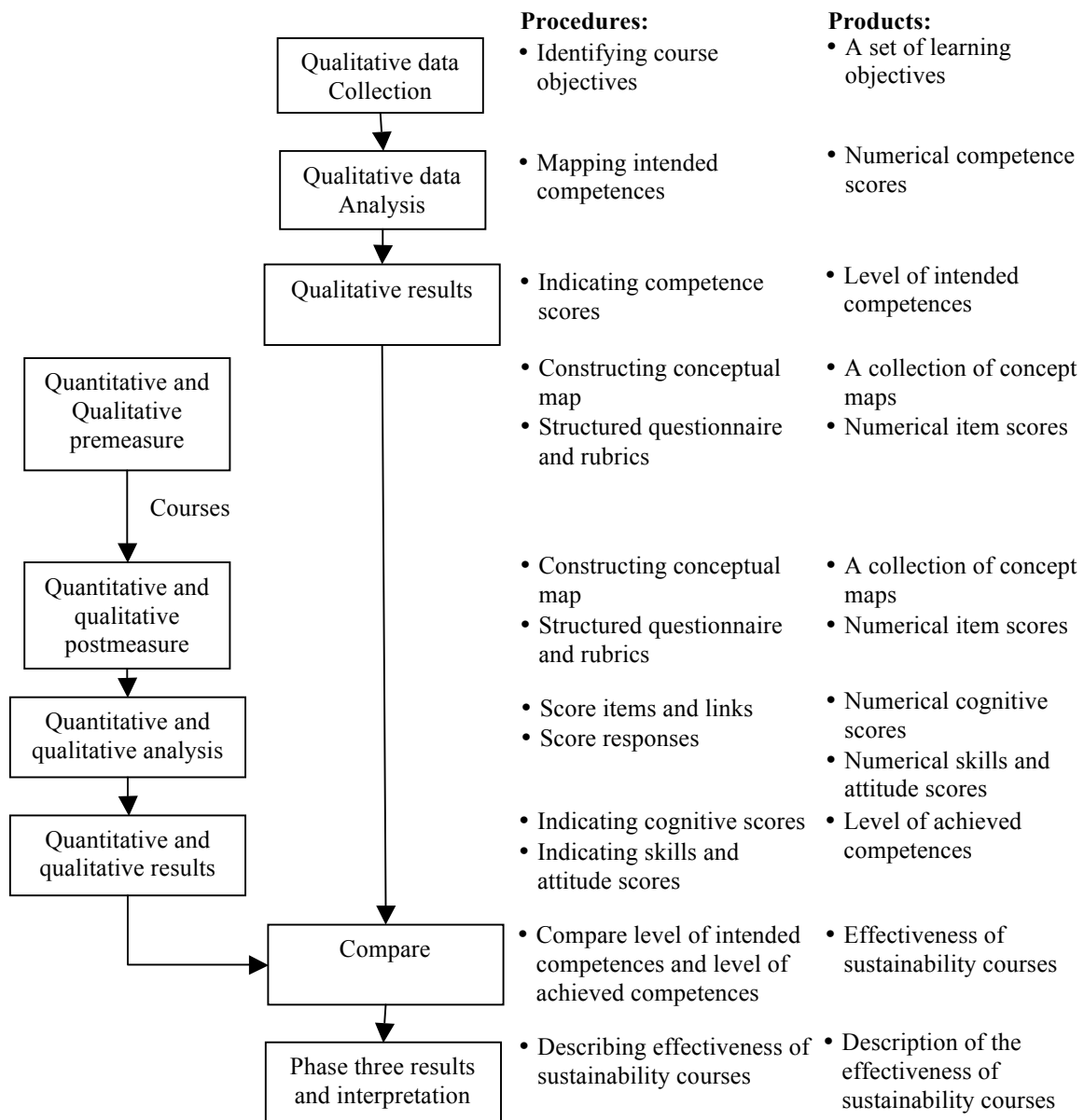


Fig. 7. Phase three – mixed methods design





The mixed methods design for phase three will address all research problems which mentioned earlier in this paper. A triangulation mixed method design will be used as the main design for evaluating students learning outcomes, on the other hand qualitative design will be used to evaluate learning objectives. Qualitative data such as skills and attitude competences will be evaluated quantitatively through rubrics scale while cognitive competences will be evaluated qualitatively through conceptual maps [4 - 7]. This phase is expected to begin on March 2013. Fig. 7 demonstrates procedures and expected products in the phase three mixed methods design.

### 3.5 Phase four: Validating design framework

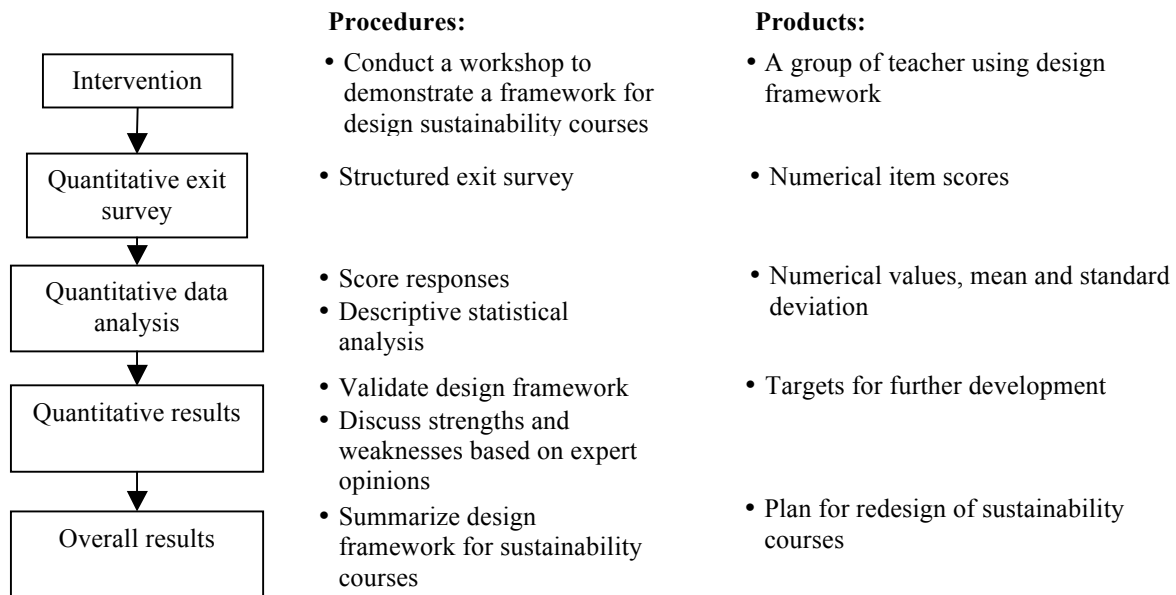


Fig. 8. Phase four – pre-experimental design

The final phase of this study is to validate a design framework as depicted in Fig. 8 and planned to execute on July 2013. The framework will be presented to a group of teachers in a workshop for developing a sustainability course. In this workshop, the teachers will use the framework and working together with facilitators to see how the framework works. A structured exit survey will be distributed to the participants to obtain feedbacks in term of the strengths and the weaknesses of using the framework for designing sustainability course.

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