Development and Evaluation of a Concept Inventory for Assessing Student Learning of Material Balance Concepts in an Undergraduate Environmental Engineering Classroom

Indumathy Jayamani and Susan J. Masten*
Department of Civil and Environmental Engineering
Michigan State University, East Lansing, MI 48824
*Corresponding author: masten@msu.edu

Abstract

The purpose of this study is twofold: I) to develop and evaluate a concept inventory that will help in the assessment of student learning of material balance concepts used in environmental engineering. It also seeks to identify additional naïve conceptions II) to gain an insight into the students' thought process while solving these conceptual problems that will help teachers design lessons better. Material balance concepts are fundamental to environmental engineering and students are expected to be able to apply these concepts in higher level courses and post-graduation. However past experiences show that, students might have certain naïve conceptions that may prevent them mastering these concepts. Concept inventories have been used widely in many fields of education and they can be used as both summative and formative assessment tools. Here we developed a beta version of a Material Balance Concept Inventory (MBCI) based on the preliminary results from a previous study. The MBCI consisted of both metadata questions and conceptual or numerical problems. Each conceptual or numerical question in the MBCI was developed online multiple choice survey with additional space provided for students to explain their thought process in arriving at the answer. This will allow us to find additional alternate conceptions. The CI will be evaluated by allowing students who have been exposed to mass balance concepts in the past to take the CI test along with collecting metadata about the participants. We believe that this study will help to create a tool that can help in assessing student learning, identifying misconceptions and eventually help in development of alternate teaching methods that will address these naïve conceptions and to teach the concepts effectively.

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Introduction and Objectives

Material balance is a fundamental 'big idea' in the field of environmental engineering introduced generally in lower level environmental engineering classrooms. A working knowledge and conceptual understanding of material balance is essential for students to learn other concepts in higher level courses that deal with topics of water and wastewater treatment, solid waste management, water quality, air pollution modeling, etc. While students pursuing their undergraduate degree in environmental engineering are often exposed to the concept of material balance in an introductory environmental engineering course during their sophomore or junior year, they are expected to continue to use and apply those material balance concepts in their upper level classes. In a successful curriculum students are expected to perform at higher levels of Blooms Taxonomy[1] in applying these concepts when applicable.

However, past experiences in environmental engineering classrooms have shown that students have difficulty mastering these concepts due to alternate conceptions that they might carry to the classroom. Teaching methods that do not emphasize the underlying assumptions in converting environmental systems to mathematical models will not allow students to obtain a strong conceptual knowledge. Also teaching methods that indirectly encourage recognizing patterns to solve material balance problems lead to negative transfer[2]. Hence there is a need to assess both learning and teaching methods that lead to such misconceptions.

Literature in cognitive research on learning and how new knowledge is obtained and constructed[2-4] suggest that as students build new knowledge on existing knowledge and therefore it is crucial for teachers to know what previous knowledge or alternate conceptions students bring into the classroom as these might have strong implications about how they learn new concepts and therefore a greater implication on teaching itself. It is very important to address these naïve conceptions before students can correctly build new knowledge.

For this purpose, concept inventories (CI) have been used in many fields[5-9] beginning with the very popular Force Concept Inventory (FCI)[10] to assess student understanding of concepts, to identify misconceptions and to help improve teaching methods. A recent study published ongoing work on development of a CI for multiple concepts in environmental engineering[11]. If designed appropriately these can also help identify different naïve conceptions students have. However there are currently no instruments that are specifically developed to test student understanding of mass balance concepts in environmental engineering. Thus, the objectives of this study are (1) to develop a concept inventory that will help in assessing student learning of core concepts in material balances and identifying the different alternate conceptions that are

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preventing the students from mastering the concepts and (2) to utilize the results of the assessment tool to develop alternate teaching methods that will help address these misconceptions effectively.

Procedure

The approach followed in achieving the objectives of this study are as follows.

1. Identify common misconceptions students have in learning concepts in mass balance in environmental engineering undergraduate classes at Michigan State University (MSU).
2. Develop a multiple choice mass balance concept inventory (MBCI) with correct answers and distractors (incorrect answers linked to certain misconceptions) based on the results from #1.
3. Evaluate the beta version of the MBCI by asking faculty and former students to complete it.
4. Administer the beta version of the MBCI to MSU students who have previously taken upper level environmental engineering classes at MSU dealing with mass balance.
5. Conduct statistical analysis on the results of stage #4 to test for its validity.
6. Refine the MBCI questions based on the results of stage #4 and stage #5.
7. Use results of stage #4 to develop alternate teaching methods that address these misconceptions.
8. Disseminate the refined MBCI through conferences and utilize it as pre and post-tests in MSU environmental engineering classes to evaluate the teaching methods developed in stage #7.

Stages 1 and 2 are completed at this time the paper is written, stage 3 is in progress and stage 4 is being planned.

Summary of completed work

Preliminary results from a previous study were utilized to create a beta version of the Material Balance Concept Inventory (MBCI)[12]. The study was conducted by assessing student performance during in-class during group work, online formative and summative assessments, homework and in exams on questions related to mass balance. The study assessed data collected from an upper level environmental engineering class from a sample size of 30. A preliminary analysis of the coded data showed that students have several naïve conceptions related to mass balance. These were related to several sub concepts that are interlinked and for which mastery is required to successfully solve mass balance problems shown in Figure 1. These include: converting the given information to an approximate schematic/model; control volume/system boundary and the state of mixing of systems; understanding the assumptions made in using ideal reactors and the difference between reactors, understanding reaction kinetics and the relationship between parameters and use of units; writing a mass balance equation (especially difficult when there are multiple substances in the system (Figure 1). Several specific naïve conceptions were identified for each of these concepts based on this analysis. For example for the concepts of "ideal reactor and their assumptions" some students ignored the assumptions of steady state systems, constant volume or immediate mixing.

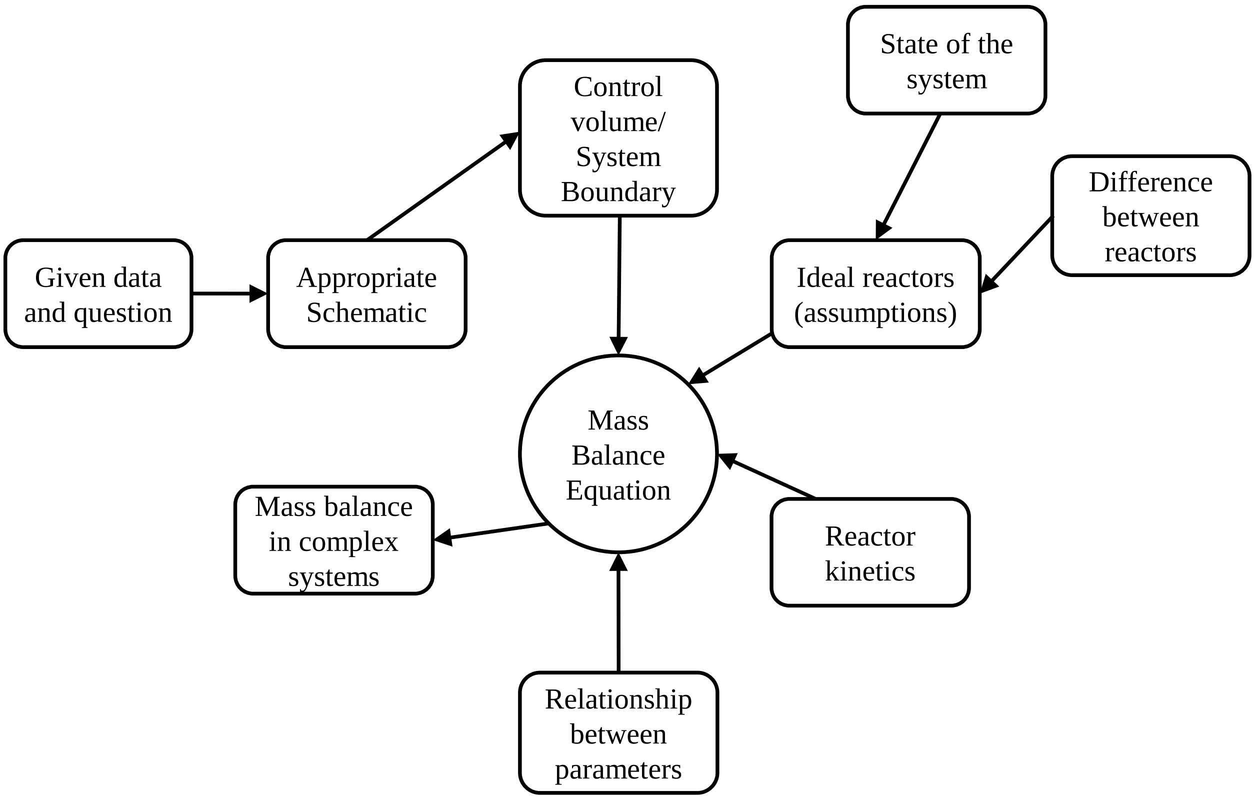
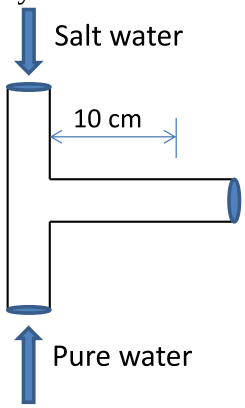


Figure 1. Sub-concepts required for solving environmental engineering mass balance problems and their relations

The concept inventory questions for the current study were formulated for several of the concepts noted in Figure (1) namely, state of mixing of system, ideal reactors and the corresponding assumptions, difference between reactors, reaction kinetics and mass balance equation. Incorrect answers from the previous study that signified specific misconceptions were also used to formulate the multiple choices for the questions (e.g., see the example presented in Figure 2). Participants will also be provided a text box with each question to explain their thought process in attempting or answering each question. This will help us in identifying additional misconceptions and also aid in stage #7 of the project to develop alternate teaching methods to address these misconceptions. Each of the concepts is also tested by one additional question in the concept inventory totaling to 18 conceptual and numerical questions. The concept inventory was developed as an online survey tool on SurveyMonkey®. In addition to the conceptual questions the online survey tool was developed to consist of additional questions that collect metadata about the participants.

Mike setup a laboratory experiment to study the growth of bacteria in water having different salt concentrations. For this he used a t-connector as shown below – through one of the inlets he passed a salt solution with a NaCl concentration of 30 mg/L at a flow rate of 20 ml/hr, through the other he pumped pure water at a flow rate of 10 ml/hr. What type of reactor can the system be best modeled as, if he wishes to determine the concentration of salt in the outlet tubing? Why?



a. Ideal reactor
b. Batch reactor
c. Completely mixed flow reactor
d. Plug flow reactor
e. A combination of c and d

Describe your rationale or thought process in answering this question.

Figure 2. Sample question on “ideal reactors” from the MBCI.

Work currently in progress

We have recently obtained approval from the MSU Institutional Review Board (IRB) to conduct the online surveys. The beta version of the MBCI is also being sent to alumni and faculty at MSU for further evaluation. The developed MBCI is also coded onto SurveyMonkey® at this time and will be disseminated to participants after it has been evaluated by several alumni of the environmental engineering program. Students who were enrolled in upper level environmental engineering classes dealing with mass balance in the last two academic years will be recruited through email for this study and will be compensated for their participation.

Next steps and Conclusion

The beta version of the MBCI will be administered to recruited students in the next few months. In addition to performing statistical analysis on the collected data to evaluate the validity and reliability of the MBCI it will also be assessed to collected identifiers that point to how students gain these misconceptions. This information will be key to the development of alternate teaching methods that will address these misconceptions in our future classrooms. We believe that as a result of this study we will develop a revised concept inventory that can be used as both formative and summative assessment tool in environmental engineering classrooms in addition to providing alternate teaching methods to teach these concepts effectively.

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