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Statics Concepts Inventory Results at Kettering University

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Abstract

This paper discusses the results of implementation of the online Statics OLI modules in several courses by the author. Although it took students a lot of additional time for doing these modules, they seemed to help many students who have poor or fair understanding of Statics concepts. The longitudinal studies of this NSF-CCLI grant will be discussed in the form of charts and tables.

Introduction and literature review

The main purpose of this paper is to present the status and results of using some of the Statics OLI modules as part of different mechanics stream of courses to identify the weaknesses of students' understanding of basics of free body diagrams, 2D equilibrium, etc., that are needed to succeed in the stream of mechanics courses taught at Kettering University. This study is part of a NSF-CCLI collaborative grant in which the author is one of the PIs. Several Statics course modules have been developed by Carnegie Melon University for adopting some or all of those in to several mechanics stream of courses taught at the collaborating and other participating universities. The mechanics stream of courses that the author chose were: Statics, Dynamics, Solid Mechanics, Machine Design and Finite Element Analysis, all of which require an excellent understanding of free body diagrams and static equilibrium (and dynamic equilibrium for Dynamics course). Other concepts such as equivalent force and moment systems, internal loads and moment of inertia area are also part of the required concepts for the students to succeed in these classes.

Development of the Statics online learning initiatives (OLI) has been drawn based on many studies carried by several authors including Steif and his team identifying the fundamental concepts and typical student errors in Statics, which affect the clear understanding of the follow on courses such as Solid Mechanics, etc. Prior modules are based on multiple choice questions that have been devised to probe students' ability to use concepts in isolation. Later on, the main PIs developed study modules in the form of Units and under each Unit several topics are covered. After the students go through the assigned modules they typically attempt the quizzes either for no credit, partial credit or for credit depending on the course for which they use these Statics modules. For example, when teaching Statics and Solid Mechanics courses, the author assigned 2 to 15 Statics course modules for credit, while for other classes (Dynamics, Machine Design and FEA), only a few modules were assigned for partial credit counted towards home work weightage. The author used these modules for several years prior to the grant period with more than 350 student participants.

Statics concepts inventory instruments in several forms have been reported by several authors listed in the references and presented at several ASEE and other educational conferences. Development of some of these instruments took several iterations and several years of study and analysis in either refining the concepts or the questions selected for the quizzes. In all, there are 18 quizzes in the Statics OLI but not all were assigned to the students. However, in some years, the author gave extra credit (added to homework) for completing all 18 quizzes. Quizzes are to be taken only after the students read the course modules. As mentioned before, the course modules and the quizzes have been developed to measure students' understanding or misconceptions of basic Statics principles. Therefore, most of these assessment tools have some authenticity for their usage.

On the basis of these reading material and quizzes and the developed instruments, one can infer which concepts students in general tend to have the most difficulties with, as well as the misconceptions that appear to be most prevalent. Larger numbers of students at several different universities have taken the Statics Concept Inventory during the past 10 years.

It is pointed out in the literature that learning is tied to effective assessment: monitoring student progress and feeding that information back just in time to students[1]. Obviously, there are many aspects of learning that can be assessed. However, if we seek to empower students to transfer the knowledge gained to new situations, then a deep understanding must be developed[2-11]. It is also documented well that in many engineering science courses, deep understanding of the subject material is usually associated with a good understanding of concepts. Therefore, it became necessary to organize the educational research in identifying core concepts and then to finding means of gauging students understanding of those concepts. With this goal in mind, several authors outlined in the reference section published their findings in many conferences. This paper describes some of the results from using Statics OLI to measure students' background in Statics concepts and the measures taken to offer help sessions to the students needing better understanding of the concepts.

Engineering Statics is a subject that is very important to draw a high level of attention as it is a pivotal course in several engineering disciplines, preparing students for a number of follow-on courses, such as dynamics, mechanics of materials, fluid mechanics, and, ultimately, design. Instructors of these follow-on courses, as well as instructors of engineering design, often feel that student understanding of Statics is a major impediment to their success in these courses. At the same time, instructors are seeking to improve instruction in Statics. Judging such instructional innovations should, at least in part, be based on their ability to advance student understanding as captured by clear, agreed upon measures. Thus assessment of conceptual understanding can help instructors to gauge the effectiveness of new teaching methods and approaches.

In the case of Newtonian mechanics, there have been efforts by the physics education community[3,4] to identify its basic concepts and associated misconceptions. These have lead to the development of instruments for measuring conceptual understanding in physics[5]. With the force Concept Inventory (of Newtonian mechanics) as a model, there also have been recent efforts in the engineering education community to develop concept inventories for a variety of engineering subjects[6], including preliminary efforts in Statics[7,8]. Little work has been devoted to identifying student misconceptions in Statics specifically. Steif did extensive work to establish a conceptual framework for Statics[9]. Four basic concept clusters were proposed in this work. The most common errors of students, identified through collection and analysis of student work, were identified, and these errors were explained on the basis of inadequacies in student understanding of the concepts grouped in to clusters. The quiz questions under these clusters consisted of multiple choice questions[9] and later these were modified to gage the students understanding of Statics concepts. These tests were administered to several students at different universities (those universities under this collaborative grant and those outside of this grant). Details of these studies can be found in references[9,11].

As mentioned above, the goal of this paper is to report the results of administering these tools among different courses to gage students' understanding of the Statics concepts and how they affect the follow on course preparation.

The most recent Statics OLI is organized in to seven Units of course concepts and material. These are:

Unit 1: Concentrated Forces and Their Effects
Unit 2: Complex Interactions between Bodies
Unit 3: Engineering Systems - Single Body Equilibrium
Unit 4: Frames and Machines
Unit 5: Trusses
Unit 6: Friction, and
Unit 7: Moments of Inertia

Each Unit contains one or more Modules of material for a total of 20 Modules under all the seven Units. As an example, Module 1 covers topic on: Representing Interactions Between Bodies; Module 2 on: Introduction to Free Body Diagrams, etc. Appendix -1 gives the list of topics/Modules. Each Module contains a Quiz with several concept questions. So in all, there are 18 to 20 Quizzes that the students can potentially take that cover the entire spectrum of a typical semester long Statics course. However, those on quarter system may not be able to cover all the topics in a Statics course, and hence some of the relevant Units, Modules and quizzes can be assigned for review by the students. Sometimes, however, students may take Dynamics and Machine Design in the same quarter in which case, the entire Statics OLI can be typically covered under these two courses. The instructors teaching these courses, if different, may have to coordinate while assigning the course material. It may be noted though that depending on the students' background, not all modules and quizzes may need to be assigned – only those Statics concepts in which majority of students may be weak need to be monitored through this process.

Results, observations and discussions

The Statics OLI have been assigned 3 to 4 times in separate Statics and Solid Mechanics Courses, one time in Dynamics course, 4 to 6 times (as a combination of required and optional), and 3 to 4 times in Finite Element Analysis course (on a combination of required and optional basis) that the author taught over the last more than 7 years at Kettering University. At this university, Statics and Solid Mechanics courses are taken only by the mechanical engineering department students, while the other engineering departments did not require those. During the early years the Statics concept test was administered as 27 multiple-choice questions. Students taking Statics and Solid Mechanics were given credit that counted either towards their quizzes or towards homework. Sometimes, a few quizzes are assigned for extra credit. Based on the instructor comments about their performance on homework and the exams, students get to choose the concepts that they think they are weak and practice the quizzes. At Kettering University, a gap exists between when Statics course is taken and the follow on courses such as Machine Design or the elective Finite Element Analysis course. For most students, the time-gap between taking Statics and Solid Mechanics is 3 months (at the minimum) to almost one year (maximum) due to the nature of schedule (co-op education) followed at Kettering.

In the following several pages, sample list of courses and the overall student performance on the quizzes is given. It may be pointed out that not all students in a class may have participated in this survey. That is, they might not have taken any quiz either because they missed deadlines set for the assignment(s), or they felt (based on their performance in the class) taking the quizzes doesn't significantly change their grade in the class, or finally, they might have taken only a few quizzes. Therefore, the statistics shown below in the next paragraph are based on the performance of majority of students in that class. Recently, a score board (or dashboard) has been developed by the lead PI's institution to understand how to interpret the results. This is based on the assessment instrument developed after several years and iterations of research by the lead PI and the other collaborators. Few sample dashboards are also presented in this paper. Dashboard (or score board) provides analysis and information about which student is weak, in what concept, and to what extent their understanding or misconception is about a concept. This provides a valuable feedback both to the student and the instructor in order to address any issues, and to help improve the performance of the student in Statics or in the follow on courses. In the course of administering the Statics OLI over the years, it was observed that several students struggle with a few common concepts. These are presented and discussed later in this section.

Course statistics:

1. **Statics: Winter 2010**
   a. Number of students participated (took quizzes) – 42
   b. Number of students who took all the assigned quizzes – 42
   c. Number of Modules/concepts/quizzes covered – 10
   d. Number of students who took additional quizzes for extra credit – 6
   e. Number of additional Modules attempted for extra credit – 7

f. Average scores (%) on each of the 10 modules is respectively:
75 75 **51** **59** 81 **66** 71 88 72 **56**

If we refer to the students' performance (bold-faced scores on Modules), it appears that these students (still taking Statics course) lacked a good understanding of those concepts, namely, Effects of Force, Effects of Multiple Forces, Couples, and Representing Engineering Connections. As a feedback to the class on these, help sessions were conducted and majority of these students' performance on the tests were improved compared to the in class quizzes that covered these concepts.

2. **Statics: Winter 2012**
   a. Number of students participated (took quizzes) – 29
   b. Number of students who took all the assigned quizzes – 22
   c. Number of Modules/concepts/quizzes covered – 14
   d. Number of students who took additional quizzes for extra credit – 6
   e. Number of additional Modules attempted for extra credit – 6
   f. Average scores (%) on each of the 14 modules is respectively:

77 88 75 **56** **48** **65** **59** **46** **56** **51** **53** **45** **49** **44**

The performance of this student batch in this year shows poor understanding of many concepts covered on Statics, indicating more work needs to be done by them, as well as, by the instructor. As a feedback to the class on these, help sessions were conducted by tutoring lab, in addition to the instructor help sessions. Majority of these students' performance on the tests and final exam has not improved significantly, and it just remained as Fair (C-minus) to Good (B-minus) grade level with an average around C-plus. Charts in figures 1 to 3 show sample scores received by the 29 students. It can be observed from figure 1 that majority of students, if not all, understand the concepts discussed in Module 1: Representing Interactions Between Bodies. Figure 2 shows the scores on Module 3: Effects of Force. Roughly half the number of students attempted this module needed more help in understanding this concept. Figure 3 shows the scores on Module 8: Statically Equivalent Loads. This shows that many students of the class needed more understanding of finding the statically equivalent loads. This has been the same problem with the senior students of Machine Design and Finite Element Analysis courses since they have an added problem due to the gap between when they took Statics and solid Mechanics courses. So in essence, these students needed to review course modules such as these to come up to speed to do what is intended to be done in those classes and not review Statics or Solid Mechanics concepts all the time. The postgraduate students taking the Finite Element Analysis class faced similar deficiencies in Statics concepts.

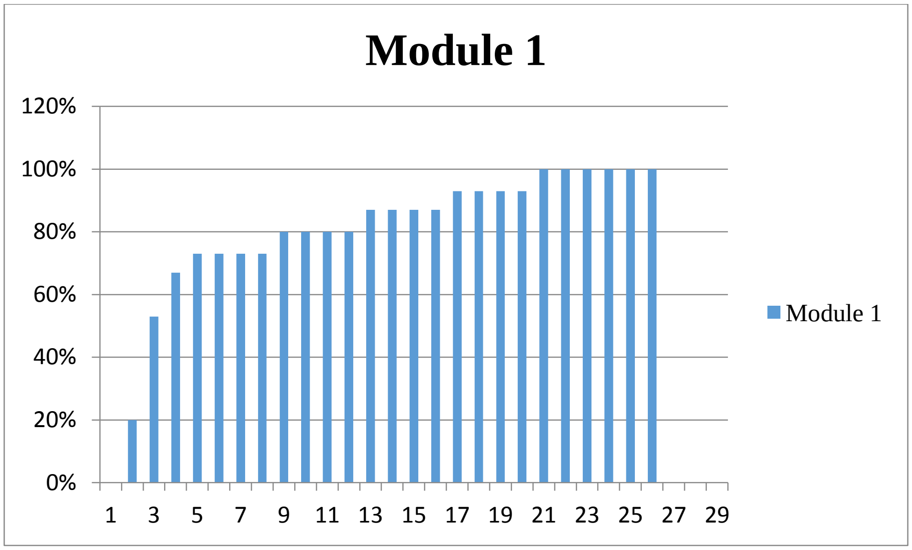

Figure 1: Student scores on Module 1: Representing Interactions Between Bodies

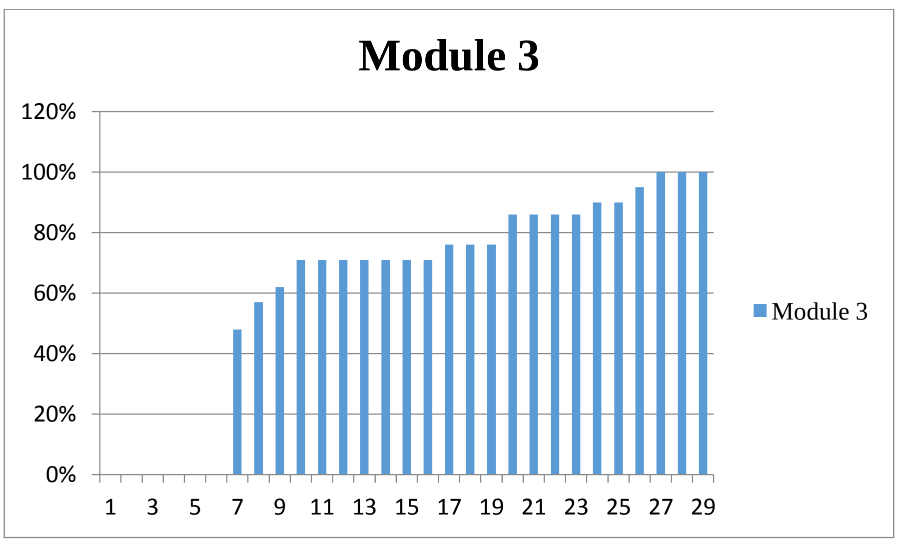

Figure 2: Student scores on Module 3: Effects of Force

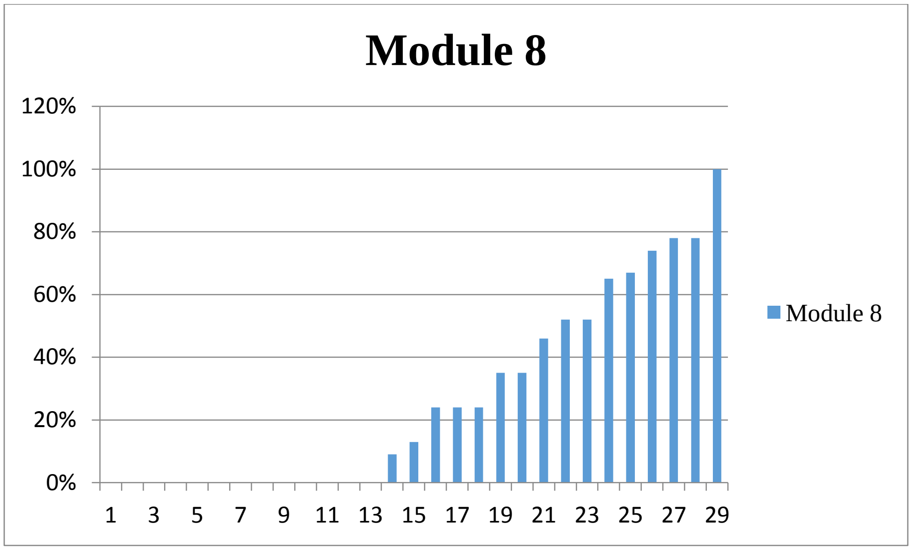

Figure 3: Student scores on Module 8: Statically Equivalent Loads

3. **Solid Mechanics:**
   a. Number of students participated (took quizzes) – 29
   b. Average number of students who took all the assigned quizzes – 25
   c. Number of Modules/concepts/quizzes covered – 17 (the first 17 Modules)
   d. Number of students who took additional quizzes for extra credit – 0
   e. Number of additional Modules attempted for extra credit – 0
   f. Average scores (%) on each of the 17 modules is shown in the graph (Figure 4 below):

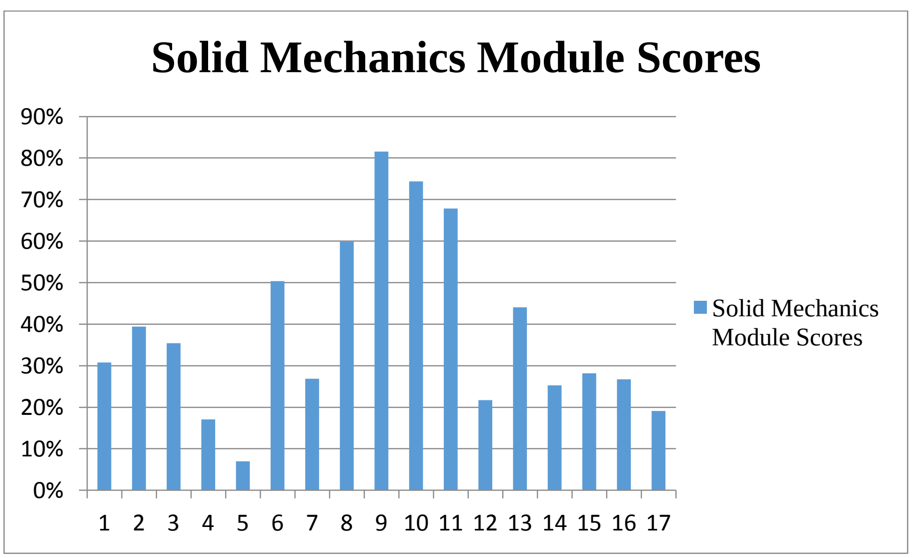

Figure 4: performance of the Solid Mechanics students on each module

Except for the acceptable performance on Modules 9, 10 and 11, the students' performance on all other modules was unacceptably low. This batch of students also had problems in Statics course per their academic transcripts. Several help sessions, tutoring labs were offered with poor attendance on the part of the students. They accepted the mediocre final grades in the course. Some of them who took the Machine Design course with the author experienced similar problems (lack of understanding of Statics concepts) in Machine Design course as well. Except for few students who made up their grades in other courses, many students of this batch graduated with mediocre grades as reported by instructors of other courses.

4. Machine Design: Fall 2011

a. Number of students participated (took quizzes) – 19
b. Average number of students who took all the assigned quizzes – 15
c. Number of Modules/concepts/quizzes covered – 5 (the first 5 from Appendix -1)
d. Number of students who took additional quizzes for extra credit – 6
e. Number of additional Modules attempted for extra credit – 6
f. Average scores (%) on each of the 5 modules is respectively:

41 82 39 17 67

The students' performance in this year shows poor understanding of the concepts even in the first Module: "Representing Interaction Between Bodies". Additionally, as in the other courses, these students' had poor understanding of concepts in Modules 3 and 4. Many of these students were taking the Machine Design course during their senior or last term at Kettering University, and they took Statics course several terms ago. As a feedback to the class and to confirm these observations, the instructor asked them to attempt the other Modules for extra credit. Many concepts from Solid Mechanics course (such as static equivalent of distributed loads, moments and couples, determining the axial and torsional stress components, etc.) 'came back' quickly to their memory than drawing free body diagrams, finding centroid and moment of composite sections such a T-Section, internal loads, etc. Few help sessions were conducted by the instructor with poor attendance (due to various reasons). The majority of these students' performance on the two tests and three to five number of quizzes has improved slightly, but not significantly. However, their performance on the final project was significantly higher due to the fact that the instructor gave them time to correct the mistakes (to redo wrong work), and also due to the group effort involved in the final project versus individual effort on tests/quizzes.

Due to the nature of the course, the tests and a few quizzes were made with open book and notes. This created problems for the majority students who did not come prepared well (since it is open all material), and began to 'read' rather than to 'refer' the book and notes occasionally for using equations and data on design charts while solving problems. In the process, they either lost time ('long exams'!), or ended up doing more work or unrelated work than what is required. Additionally, although the instructions on the question paper mention not to rewrite equations or to redraw the same sketches given on the question while answering, many students did exactly did the same, thus running out of time. The author tried administering group exams (through a randomly selected process or through student selected process) during some years to ease their test anxiety, but many did not the coordinate well to complete or to do well on the exams. However, they felt that group tests rather than individual tests are helpful to them. Sometimes, the author set different exam to different groups so that each group can communicate freely between members. The overall performance in this course has been better (grades of B to A) than those students in Statics and Solid Mechanics courses, where, more individual effort is required.

5. **Dynamics of Particles and Rigid Bodies: Summer 2011**
    a. Number of students participated (took quizzes) – 23
    b. Average number of students who took all the assigned quizzes – 17
    c. Number of Modules/concepts/quizzes covered – 8 (the first 8 from Appendix -1)
    d. Number of students who took additional quizzes for extra credit – 6
    e. Number of additional Modules attempted for extra credit – 6
    f. Average scores (%) on each of the 8 modules is respectively:

71	67	49	23	10	20	18	7

The results from this batch of students show unacceptably low scores in several Statics concepts, including the free body diagrams. Overall, this batch of students did fairly well, mostly scoring C^- and B-grades. The final course in this study is the mezzanine level elective course on Finite Element Analysis. This course is taken by senior undergraduates and graduate on campus and off campus students. The statistics for this course as are as follows:

6. **Applied Finite Element Analysis:**
    g. Number of students participated (took quizzes) – 22
    h. Average number of students who took all the assigned quizzes – 14
    i. Number of Modules/concepts/quizzes covered – 5
    j. Number of students who took additional quizzes for extra credit – 0
    k. Number of additional Modules attempted for extra credit – 0
    l. Average scores (%) on each of the 4 modules is respectively:

27	76	4	5	76

The results from this batch of students show that they are weak in Statics Modules 3 and 4 (just all other students that the author taught). Some students failed to take the tests on time (didn't meet the deadline), while a few of them didn't think it is necessary for them to review Statics concepts. Finite Element Analysis course requires that all homework, class work and exam results be validated by simple hand calculations using Statics and Solid Mechanics concepts for the simplified models. Therefore, several students had problems with calculating stresses and deflections of models using simplified mechanics approach. Due to the same problem, the results from direct stiffness method solved by a math tool (such as MatLab) or a CAE tool (such as UG NX or I-DEAS) could not be correctly interpreted by many students of this batch. Some help sessions and persistent reading and review assignments of solid mechanics improved their final learning experiences in the class. It was observed that the off campus students performed better than the on campus students on the Statics OLI. All off campus students work in industry with more industrial experience and maturity to focus on learning course material. Their performance (overall GPA) in all the graduate courses affects the financial support they normally received from their work.

The sample Dashboard from Statics OLI for the Statics Winter 2012 course is presented below. This shows that there are 27 students who participated in taking this quiz. It also shows more statics about how much % activities have been started. Each student's response can be found by clicking on one of the tabs at the left bottom of this screenshot.

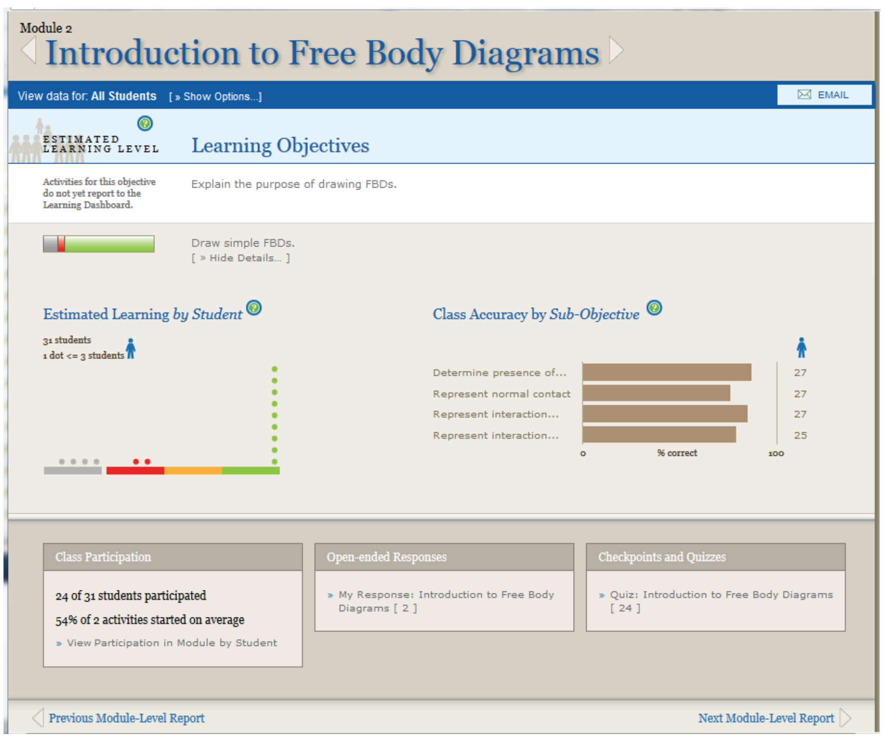

Figure 5: Sample Dashboard showing course inventories by Module and by student

Conclusions

Traditionally, since many students do not come prepared for a class (see or hear material first time in the class), many authors tried to assign them online reading material to work through and when they come to class, quiz them on the material they learned. In the case of implementation of Statics OLI, students are asked to read the material first and take end of module quiz for credit (or for practice).

Overall, several students lacked skills in drawing correct free body diagrams. This is due to a poor understanding of the concept behind what a free body diagram is, why it should be drawn and how to represent the reaction loads. By looking at their responses, it is clear that students continued to exhibit several misconceptions about how to draw correct free body diagrams although in some cases, they found the correct reaction loads. The other major problem was in their difficulty to understand internal loads, equivalent loads, and area moments of inertia, particularly of hollow sections and rectangular sections with respect how the loads are applied. These concepts are essential to correctly solve the upper division Solid Mechanics, Machine Design and FEA classes. Several help sessions and other online tutorials and freeware were used to enhance their understanding of these, which helped somewhat in their better understanding of those concepts. Determining reaction loads due to distributed loads is another major hurdle for carrying out the design problems.

In the end, however, more studies and teaching techniques are required to design course modules for Statics using everyday examples (E^3)[12] that may perhaps help the students. Some remedies at Kettering University are taken to reinforce students to take Statics, Solid Mechanics, Dynamics and Machine Design in sequence and not postpone, causing gaps in knowledge.

Acknowledgements

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12. E^3 Everyday Examples.

Appendix – I (list of topics/Modules covered in Statics OLI)

1. Representing Interactions Between Bodies
2. Introduction to Free Body Diagrams
3. Effects of Force
4. Effects of Multiple Forces
5. Equilibrium Under 2D Concentrated Forces
6. Couples
7. Statically Equivalent Loads
8. Simplifying 3D Loadings
9. Center of Gravity and Centroid
10. Representing Engineering Connections
11. Drawing FBDs of a Single Subsystem
12. Equilibrium of a Single Subsystem
13. Choosing a Solvable Subsystem
14. Drawing FBDs of Multiple Subsystems
15. Solving Multiple Subsystems
16. Method of Joints
17. Method of Sections
18. Friction (did not specifically require the students to do)
19. Second Moment of Area
20. Mass Moment of Inertia (used only for Dynamics course)