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A Web-Based Interactive Intelligent Tutoring System for Enhancing Student Learning in a Foundational Engineering Dynamics Course*

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Extensive literature review shows that no intelligent tutoring systems (ITSs) were developed for engineering dynamics, a second-year core course that nearly all undergraduates majoring in mechanical, aerospace, civil, environmental, or biomedical engineering are required to take. This paper describes two innovative, web-based, interactive ITS modules that we developed for and implemented in an engineering dynamics course to help students learn how to apply the Principle of Work and Energy, one of the most important dynamics principles, to solve particle and rigid-body dynamics problems. This paper describes in detail how the two ITS modules were designed, and specifically such aspects as the determination of learning objectives, the design of corresponding dynamics problems that the ITS modules address, the selection of ITS authoring software, and the design of the layout of the interactive computer graphical user interfaces of the ITS modules. Two cohorts of engineering undergraduates during a control semester and a treatment semester participated in the present study. The results of pretests and posttests in the control and treatment semesters show that the two ITS modules increased class-average student learning gains by 36.8% and 43.0%, respectively. In an anonymous questionnaire survey that was administered at the end of the treatment semester, many students used the words "hints" and "step-by-step process" to describe how the ITS modules enhanced their learning. It is suggested that given their level of flexibility, intelligent tutoring systems should be used as a supplemental tool to enhance learning, rather than a tool to completely replace students' experiences with human instructors and human tutors.

Keywords: engineering dynamics; interactive web-based intelligent tutoring system; student learning; conceptual understanding; procedural skills

1. Introduction

1.1 Student learning challenges in engineering dynamics

Engineering dynamics is a foundational course that nearly all undergraduates majoring in mechanical, aerospace, civil, environmental, or biomedical engineering are required to take. This second-year core course covers a broad spectrum of fundamental concepts (e. g., velocity, acceleration, force, work, energy, impulse, momentum, and vibration) and important principles (e.g., the Principle of Work and Energy and the Principle of Impulse and Momentum) and is a fundamental building block for many advanced studies in subsequent courses [1].

Nevertheless, engineering dynamics is widely regarded as "one of the most difficult courses that engineering students encounter during their undergraduate study" [2]. In our recent survey, students were asked about their perspectives on dynamics. More than 60% of the students surveyed used phrases such as "much harder than statics," "extremely difficult," "very challenging," and "are afraid of it." Existing research has established that many students have high learning anxiety relating to dynamics [3]. The inability to successfully complete the course often results in high attrition. Barrett et al. [4] reported that, on the 2009 standard Fundamentals of Engineering examination given in the USA, the national average score on the dynamics exam was only 53%.

Conceptual understanding and procedural skills are two critical and essential requirements for students to succeed in learning engineering dynamics. To solve an engineering dynamics problem, a student must have a solid conceptual understanding of the problem first, and then must have essential procedural skills to correctly solve the problem. Lacking either conceptual understanding or procedural skills would result in incomplete or incorrect solutions to dynamics problems.

In the present study, conceptual understanding is defined as a student's mastery of the true meaning and implications of dynamics concepts and principles. In the context of dynamics, conceptual understanding is more than just conceptual "knowledge"—the latter term meaning that a student is simply aware of facts associated with certain dynamics concepts and principles. For example, if a student knows that the Principle of Conservation of Energy involves both kinetic energy and potential

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energy, and that the total energy is conserved in a dynamics problem, the student has conceptual "knowledge" of the Principle of Conservation of Energy. However, if to solve a dynamics problem regarding a rigid body subjected to a frictional force, the student still applies the Principle of Conservation of Energy, rather than the Principle of Work and Energy, the student does not truly understand the Principle of Conservation of Energy. The student incorrectly selects this principle for a wrong application and does not truly understand the limitations and applicable range of this principle; thus the student has no conceptual understanding of this principle.

In the present study, procedural skills are defined as a student's skills for applying his or her conceptual (qualitative) understanding to set up math equations to generate a numerical (quantitative) solution to a dynamics problem. In the context of dynamics, procedural skills are more than just procedural "knowledge"—the latter term meaning that a student is simply aware of general steps involved in solving a dynamics problem. For example, in solving a rigid-body dynamics problem, if a student knows that he or she needs to draw a free-body diagram and a kinetic diagram, then apply Newton's Second Law to set up mathematical equations, and finally solve the equations to generate a numerical solution, the student has procedural "knowledge" of the problem. However, if the student gets stuck in the very first step and cannot correctly draw a free-body diagram or a kinetic diagram, the student has no necessary procedural skills to solve this problem.

Existing research has shown that many students lack conceptual understanding and procedural skills to correctly solve dynamics problems [3–6]. For example, when calculating the kinetic energy for a rigid body undergoing a general plane motion, students consider only the translational component and miss the rotational component of the kinetic energy. Many students cannot create graphical representations (e.g. a free-body diagram, kinetic diagram, and momentum diagram) of a dynamics problem. Neither can they set up mathematical equations to quantify the relationships among relevant variables [7].

1.2 *Intelligent tutoring systems*

As an interactive learning tool, intelligent tutoring systems (ITSs) have received growing attention in the engineering education community in recent years [8–10]. In an ITS, students solve technical problems with the guidance of a virtual tutor. Students can ask the virtual tutor questions or request hints on what to do next during problem solving, similar to what occurs in a real classroom environment where students ask a human tutor questions or request hints. The ITS also enables students to learn anytime (24/365), anywhere, and at their own pace.

Research evidence [11–15] has shown that a properly-designed ITS improves student learning across all STEM (science, technology, engineering, and mathematics) disciplines, especially in large classes where instructor-student interaction and one-on-one tutoring time are limited due to class size. For example, Butz [11] found that an interactive multimedia ITS improved student learning in engineering circuits courses. The students in an experimental group scored higher on all relevant performance measures than those in a control group.

1.3 *Innovation of the present study*

The goal of this study is to develop and assess two ITS modules for an undergraduate engineering dynamics course. The two modules aim to help students learn how to apply the Principle of Work and Energy, one of the most important principles of dynamics, to solve particle and rigid-body dynamics problems, respectively. The Principle of Work and Energy states that the work done by all of the external forces (and moments if applicable) on a particle or a rigid body when the particle or the rigid body moves from position 1 to position 2 is equal to the change in the particle's or the rigid body's potential energy [1]. It must be pointed out that these two modules are not intended to replace regular classroom instructions, but to serve as a supplemental tool for students to learn the Principle of Work and Energy.

We have performed an extensive literature review using a variety of popular databases such as EBSCOhost, ERIC, Web of Science, annual American Society for Engineering Education conference proceedings (1995–2012), and annual Frontiers in Education conference proceedings (1995–2012). The results show that all the existing ITSs, such as CycleTalk, Genetics Tutors, and Politeness Tutor [8, 16–19], were developed for courses such as mathematics, physics, forensic biology, computer-aided modeling and design, and circuit analysis. With the exception of our own work, no other ITS has been developed for any engineering dynamics courses.

For example, Aberšek and Popov [8] developed an ITS for the design, optimization, and manufacture of gears and gearing. The ITS was employed in an undergraduate computer-aided design and manufacturing course in mechanical engineering. With the ITS, students learned important factors in gear design, such as the geometrical dimensions of gears, loading, material characteristics, rotating speeds, the material spring constant, and so on. Soh and

Gupta [19] developed an ITS for statics courses that were offered to first-year engineering undergraduates. Their ITS system allowed students to learn statics concepts and problem solving through examples. When using their ITS system, students had to respond to some technical questions included in example problems. If a student's response was incorrect, the ITS system would guide the student toward the correct solution without giving away the correct solution immediately.

1.4 Research questions of the present study

The present study has the following two research questions:

1. To what extent did the developed ITS modules help students learn how to apply the Principle of Work and Energy to solve particle and rigid-body dynamics problems?
2. What were students' attitudes toward and experiences with the developed ITS modules?

By answering the above two questions, we would be able to continuously improve the design of ITS to better meet the needs of student learning in engineering dynamics and to share our experiences and lessons with the international education community.

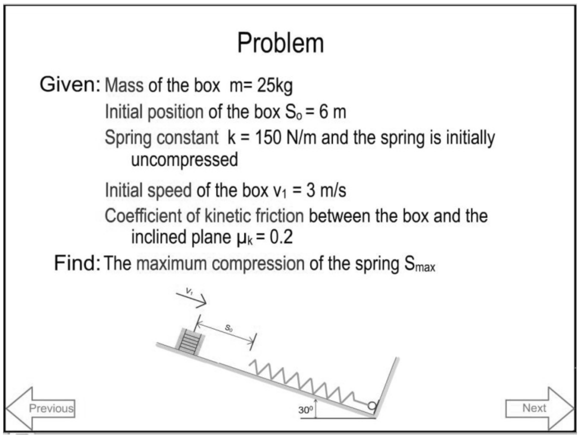
In the following sections of the paper, how the two web-based interactive ITS modules were developed is described first. Then, the research method is described in detail. Next, the research results are presented and analyzed, including the comparison of student learning gains in control and treatment semesters, and student evaluations of the ITS modules. Two primary limitations of the present study are also discussed. Finally, the answers to the two research questions are summarized at the end of the paper.

2. Development of web-based interactive ITS modules for engineering dynamics

Two ITS modules were developed from the present study to help students learn how to apply the Principle of Work and Energy to solve dynamics problems. One module focused on a particle dynamics problem, and the other module focused on a rigid-body dynamics problem. In designing the two ITS modules, the following seven steps were involved: 1) determine learning objectives of the ITS modules; 2) design corresponding dynamics problems for the ITS modules to address; 3) select ITS authoring software; 4) design the layout of interactive computer graphical user interfaces (GUIs) of the ITS modules; 5) design a set of hints that students may need when using the ITS modules; 6) write computer codes using Adobe Flash and the ITS authoring software selected in Step 3, and 7) test the ITS modules through iterative debugging processes. Because the purpose of this paper is not to describe the process of writing and debugging computer codes, the following paragraphs only provide the details of Steps 1 through 5.

Step 1: Determine learning objectives of the ITS modules. Both modules address the Principle of Work and Energy. However, Module 1 focuses on particles and Module 2 on rigid bodies. For example, the learning objectives for ITS Module 1 are: determine the kinetic energy of a particle, determine the work done by a force, and apply the Principle of Work and Energy to solve a particle dynamics problem.

Step 2: Design corresponding dynamics problems that the ITS modules addressed. Two dynamics problems are designed to address learning objectives. These two new dynamics problems, as shown in Figs. 1 and 2, respectively, help students develop both conceptual understanding and procedural skills when they learn the Principle of Work and Energy. Fig. 1 is a particle dynamics problem in

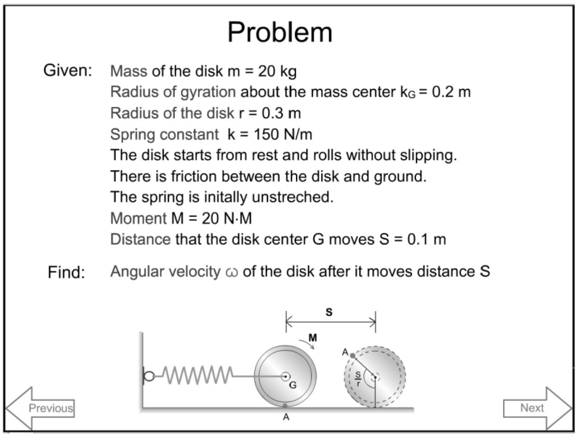


Problem

Given: Mass of the box m= 25kg
Initial position of the box S_0 = 6 m
Spring constant k = 150 N/m and the spring is initially uncompressed
Initial speed of the box v_1 = 3 m/s
Coefficient of kinetic friction between the box and the inclined plane μ_k = 0.2

Find: The maximum compression of the spring S_{max}

Fig. 1. A particle dynamics problem designed for ITS Module 1.



Problem

Given: Mass of the disk m = 20 kg
Radius of gyration about the mass center k_G = 0.2 m
Radius of the disk r = 0.3 m
Spring constant k = 150 N/m
The disk starts from rest and rolls without slipping.
There is friction between the disk and ground.
The spring is initally unstreched.
Moment M = 20 N·M
Distance that the disk center G moves S = 0.1 m

Find: Angular velocity ω of the disk after it moves distance S

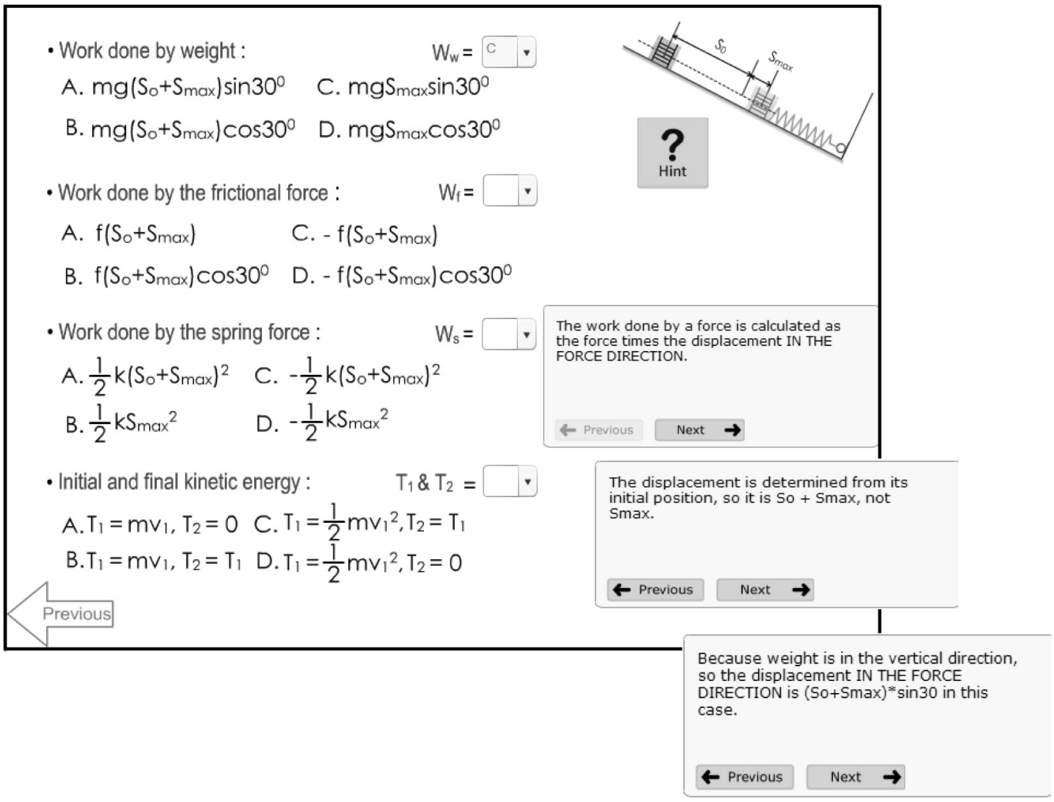
Fig. 2. A rigid-body dynamics problem designed for ITS Module 2.

which a box (treated as a particle in this case) slides down along an inclined and non-smooth surface, and then hits and compresses a spring. Students learned how to determine the maximum compression of the spring when the box stops. Fig. 2 is a rigid-body dynamics problem in which a uniform, rotating disk is subjected to an external moment and a spring force. Students learned how to determine the angular velocity of the disk when it rotates over a given distance.

Step 3: Select ITS authoring software. Among a variety of ITS authoring software tools available, we selected the Cognitive Tutor Authoring Tools (CTAT) to develop our ITS modules. The CTAT is one of the most popular tutor authoring software developed at Carnegie Mellon University for authoring tutor behavior [8, 20]. The CTAT provides a set of specialized tutoring widgets to create computer graphical user interfaces (GUIs) in Adobe Flash in a drag-and-drop manner. In the present study, the CTAT was employed to create example-tracing tutors. This type of tutor can be created quickly without programming, but requires problem-specific authoring.

Step 4: Design the layout of interactive GUIs of the ITS modules. We considered two primary factors in designing the GUI layout. First, it must provide students with a variety of interactions, such as requesting hints, selecting correct answers before proceeding to the next step, and changing variables to see how different values of a variable affect the final solution to the problem. Second, students' cognitive load for learning with each GUI must be controlled at an appropriate level. Research [21] has revealed that student learning outcomes are not optimum if cognitive load is too high or too low. In addition, each GUI serves a particular purpose and facilitates student learning of a particular topic (or sub-topic). Figs. 3 and 4 provide example GUIs for ITS Modules 1 and 2, respectively. In these two examples, students must select correct answers before proceeding to the next problem-solving step. If a student selects a wrong answer, the ITS modules provide a detailed explanation for why the answer is wrong.

Step 5: Design a set of hints that students may need when using the ITS modules. Useful hints are particularly helpful for students to learn problem solving. We designed a set of hints based on common conceptual misunderstanding and procedural mistakes of students when students learn the Principle of Work and Energy. Figs. 3 and 4 also contain a set of hints associated with a particular learning topic or sub-topic. The following paragraphs provide five examples of hints that can be employed when students learn how to calculate the



• Work done by weight : W_w = C

A. $mg(S_o+S_{max})\sin 30^0$ C. $mgS_{max}\sin 30^0$

B. $mg(S_o+S_{max})\cos 30^0$ D. $mgS_{max}\cos 30^0$

• Work done by the frictional force : W_f =

A. $f(S_o+S_{max})$ C. $-f(S_o+S_{max})$

B. $f(S_o+S_{max})\cos 30^0$ D. $-f(S_o+S_{max})\cos 30^0$

• Work done by the spring force : W_s =

A. $\frac{1}{2}k(S_o+S_{max})^2$ C. $-\frac{1}{2}k(S_o+S_{max})^2$

B. $\frac{1}{2}kS_{max}{}^2$ D. $-\frac{1}{2}kS_{max}{}^2$

• Initial and final kinetic energy : T_1 & T_2 =

A. $T_1 = mv_1, T_2 = 0$ C. $T_1 = \frac{1}{2}mv_1{}^2, T_2 = T_1$

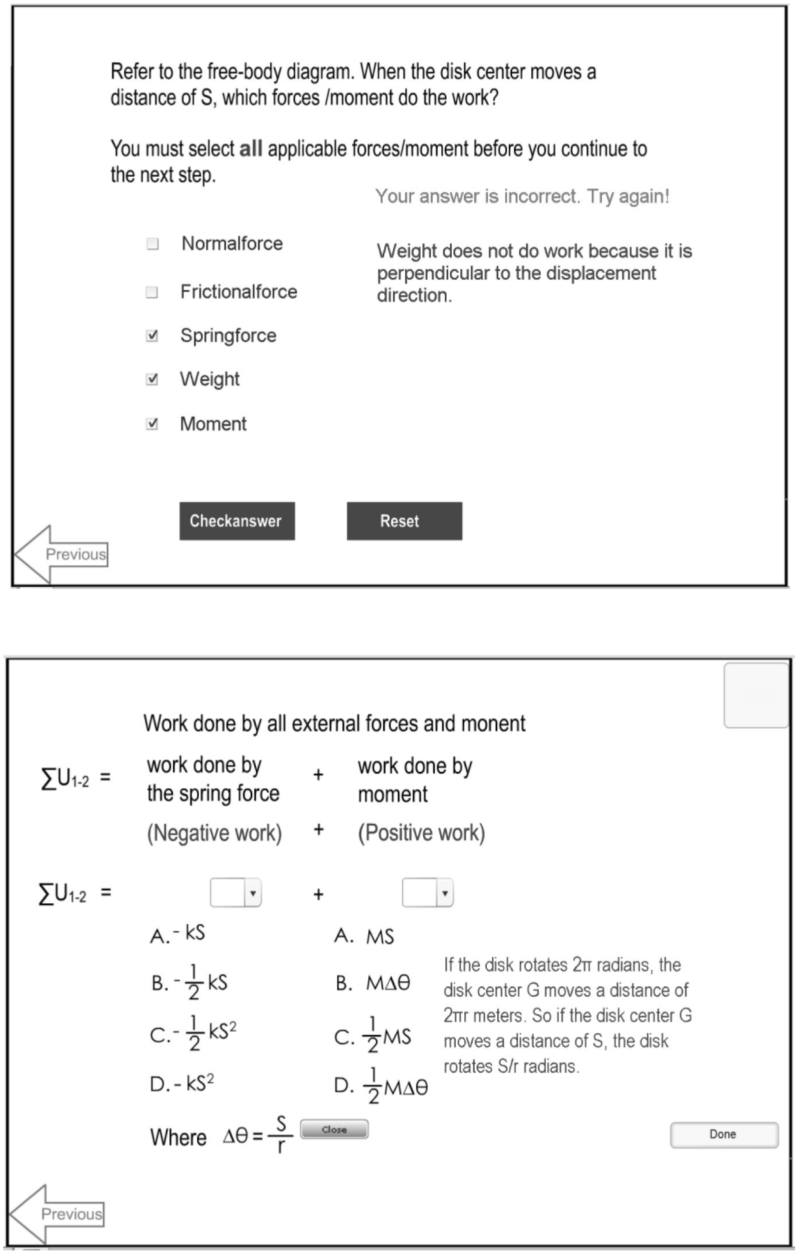
B. $T_1 = mv_1, T_2 = T_1$ D. $T_1 = \frac{1}{2}mv_1{}^2, T_2 = 0$

The work done by a force is calculated as the force times the displacement IN THE FORCE DIRECTION.

The displacement is determined from its initial position, so it is So + Smax, not Smax.

Because weight is in the vertical direction, so the displacement IN THE FORCE DIRECTION is (So+Smax)*sin30 in this case.

Fig. 3. An example graphical user interface (GUI) and hints for ITS Module 1.



Refer to the free-body diagram. When the disk center moves a distance of S, which forces /moment do the work?

You must select **all** applicable forces/moment before you continue to the next step.

Your answer is incorrect. Try again!

☐ Normalforce

☐ Frictionalforce

☑ Springforce

☑ Weight

☑ Moment

Weight does not do work because it is perpendicular to the displacement direction.

Work done by all external forces and monent

$\sum U_{1\text{-}2}$ = work done by the spring force + work done by moment

(Negative work) + (Positive work)

$\sum U_{1\text{-}2}$ = ☐ + ☐

A. $-kS$	A. MS
B. $-\frac{1}{2}kS$	B. $M\Delta\theta$
C. $-\frac{1}{2}kS^2$	C. $\frac{1}{2}MS$
D. $-kS^2$	D. $\frac{1}{2}M\Delta\theta$

Where $\Delta\theta = \frac{S}{r}$

If the disk rotates 2π radians, the disk center G moves a distance of 2πr meters. So if the disk center G moves a distance of S, the disk rotates S/r radians.

Fig. 4. Two example graphical user interfaces (GUIs) for ITS Module 2.

work done by weight and the work done by a frictional force. Note that a higher-order hint (e.g., the second or the third hint) addresses deeper conceptual misunderstandings or bigger procedural mistakes that students may have during problem solving. The critical information included the hints is highlighted in capital letters in order to catch students' attention.

Examples of hints for calculating the work done by weight:

- The first hint: The work done by a force is calculated as the force times the displacement IN THE FORCE DIRECTION.
- The second hint: The displacement is determined from its initial position, so it is $S_o + S_{max}$, not S_{max}.
- The third hint: Because weight is in the vertical direction, the displacement IN THE FORCE DIRECTION is $(S_o + S_{max}) \times \sin 30^\circ$ in this case.

Examples of hints for calculating the work done by the frictional force:

- The first hint: The frictional force and the displacement are in opposite directions, so the frictional force does negative work.
- The second hint: The displacement IN THE FORCE DIRECTION is $S_o + S_{max}$, not $(S_o + S_{max}) \times \cos 30^\circ$, in this case.

3. Research method

3.1 Quasi-experimental research design

A quasi-experimental research method [22] was implemented to answer the first research question. The quasi-experimental method involved two cohorts of student participants in a control semester and a treatment semester. The dynamics course was taught by the same instructor (i. e., the first author of this paper) in both semesters. The same set of pretests and posttests were implemented in both semesters.

For each of the control and treatment semesters, student learning gains were calculated using the following formula [23]:

$$\text{Learning gain} = \frac{\text{Posttest score (\%)} - \text{Pretest score (\%)}}{100\% - \text{Pretest score (\%)}} \quad (1)$$

The effect of the ITS modules on student learning can then be determined by comparing student learning gains between students in the control and treatment semesters.

3.2 Assessment questions for use in pretests and posttests

A total of 13 technical assessment questions were designed and implemented in pretests and posttests to assess student learning of similar dynamics problems. Out of 13 assessment questions, six questions were designed for ITS Module 1, and seven questions for ITS Module 2. Table 1 summarizes the conceptual understanding and procedural skills that each question assessed. The following paragraphs provide two representative assessment questions:

Assessment question 5 of ITS Module 1 asks students to calculate the initial and the final kinetic energy of the box when the box moves down along an inclined surface. The question states: The initial kinetic energy (T_1) of the box and the final kinetic energy (T_2) of the box are:

(A) T_1 = 100 Joule, T_2 = 0 Joule
(B) T_1 = 100 Joule, T_2 = 100 Joule
(C) T_1 = 200 Joule, T_2 = 200 Joule
(D) T_1 = 200 Joule, T_2 = 0 Joule

Assessment question 7 of ITS Module 2 asks students to calculate the angular velocity of a disk after the disk moves a certain distance along a horizontal plane. The question states: The angular velocity ω of the disk after it moves distance S is:

(A) 0.96 rad/s
(B) 2.13 rad/s
(C) 3.30 rad/s
(D) 4.47 rad/s

Statistical t-tests were performed to determine if there were no statistically significant differences in the mean pretest scores of two cohorts of students in the control and treatment semesters.

3.3 Questionnaire survey to assess students' attitudes and experiences

An anonymous questionnaire survey was administrated at the end of the treatment semester to answer the second research question. The questionnaire survey included three Likert-type questions and two open-ended, free-response questions, as shown in Table 2. The meaning of two pedagogical terms, "conceptual understanding" and "procedural skills," were explained to all student participants (i.e., engineering students who might not know the definition of terminologies used by education researchers) before students responded to the questionnaire survey.

3.4 Student participants

Two cohorts of undergraduate engineering students who were enrolled in a dynamics course participated in the present study. Table 3 lists the number of

Table 1. Students' conceptual understanding and procedural skills that were assessed

ITS module	Assessment question	Conceptual understanding and procedural skills that were assessed
1	1	Assess if students can understand and calculate a frictional force along an inclined surface.
1	2	Assess if students can understand and calculate the work done by weight.
1	3	Assess if students can understand and calculate the work done by a frictional force.
1	4	Assess if students can understand and calculate the work done by a spring force.
1	5	Assess if students can understand and calculate the kinetic energy of a particle.
1	6	Assess if students can synthesize all conceptual understanding and procedural skills to finally solve the problem.
2	1	Assess if students can understand and correctly draw a free-body diagram.
2	2	Assess if students can understand and calculate the kinetic energy of a rigid body.
2	3	Assess if students can identify the forces or moments that do work.
2	4	Assess if students can understand and calculate the work done by a spring force.
2	5	Assess if students can understand and calculate the work done by a moment.
2	6	Assess if students can calculate the angle that a disk rotates.
2	7	Assess if students can synthesize all conceptual understanding and procedural skills to finally solve the problem.

Table 2. Questionnaire survey to assess students' attitudes toward and experiences with the developed ITS modules

Item	Content
1	I would like to rate the overall quality of the ITS modules as: Very low 1 2 3 4 5 Very high.
2	The ITS modules enhanced my conceptual understanding of dynamics problems: Highly disagree 1 2 3 4 5 Highly agree.
3	The ITS modules enhanced my procedural skills to solve dynamics problems: Highly disagree 1 2 3 4 5 Highly agree.
4	Describe how the ITS modules enhanced my conceptual understanding (if any).
5	Describe how the ITS modules enhanced my procedural skills (if any).

Table 3. Student participants

Semester	ITS Module 1	ITS Module 2
Control	n = 62	n = 55
Treatment	n = 44	n = 36

student participants in the control and treatment semesters for each ITS module. Note that not every student in the class participated in assessments with both modules. Forty-four students in the treatment semester responded to the questionnaire survey. The majority of student participants (79.5%–87.1% in different semesters) were males, which is typical in engineering study programs in the USA. The largest participant groups were mechanical and aerospace engineering (MAE) majors. The second largest participant groups were civil and environmental engineering (CEE) majors, or biological engineering (BE) majors.

4. Results and analysis

4.1 Comparison of student learning gains in control and treatment semesters

The results of statistical *t*-tests show that there were no statistically significant differences in the mean pretest scores of two cohorts of students in the control and treatment semesters. The p value obtained from *t*-tests (on the mean pretest scores) was 0.257 for ITS Module 1 and 0.924 for ITS Module 2. This means that the two cohorts of students in the control and treatment semesters were comparable.

Table 4 summarizes the class-average learning gains for all assessment questions in the control and treatment semesters. As seen from Table 4, class-average learning gains were 12.9% (for ITS Module 1) and 7.0% (for ITS Module 2) in the control semester when students learned from regular classroom lectures only. Class-average learning gains increased to 49.7% (for ITS Module 1) and 50.0% (for ITS Module 2) in the treatment semester when students learned from regular classroom lectures and the two ITS modules as well. The two ITS learning modules increased class-average student learning gains by 36.8% and 43.0%, respectively.

Table 4. Class-average learning gains for all assessment questions of each ITS module

Semester	ITS Module 1	ITS Module 2
Control	12.9%	7.0%
Treatment	49.7%	50.0%

Figs. 5 and 6 further show the comparison of student learning gains for each assessment question of ITS Modules 1 and 2, respectively. In Fig. 6, the class-average student learning gain for assessment question No. 3 was zero in the control semester. Figs. 7 and 8 show the percentage of students who chose correct answers in the control and treatment semesters for ITS Modules 1 and 2, respectively. In Fig. 8(a), the percentages of students who chose correct answers to assessment question No. 3 were the same in the pretest and the posttest in the control semester. The following observations were made from Figs. 5–8.

As seen from Figs. 5 and 7, ITS Module 1 significantly increased student learning gains for assessment questions 2, 3, 4, and 5. However, it did not substantially increased student learning gains for assessment questions 1 and 6. As shown clearly in Fig. 7b, the percentage of students who chose correct answers for assessment questions 1 and 6 was slightly higher in posttests than in pretests in the treatment semester. As shown in Table 1, assessment question 1 focused on the understanding

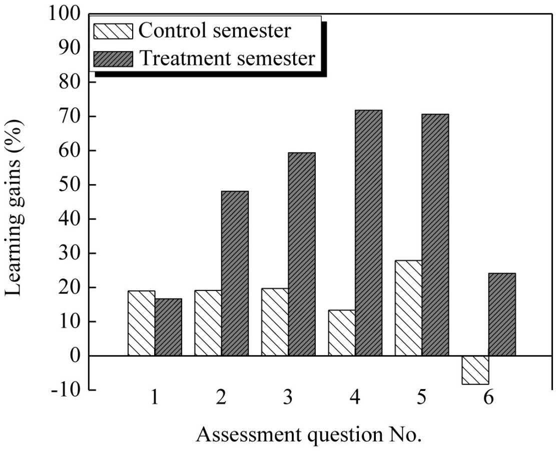


Fig. 5. Comparison of student learning gains for each assessment question of ITS Module 1.

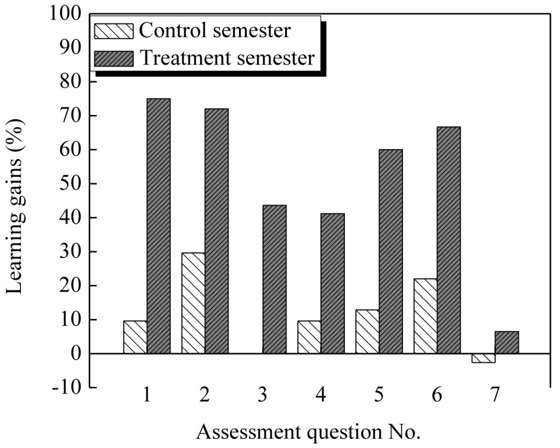


Fig. 6. Comparison of student learning gains for each assessment question of ITS Module 2.

and calculation of a frictional force along an inclined surface. It was found that some students could not choose correct geometric (sine or cosine) functions to solve question 1 due to their poor mathematical skills. Assessment question 6 examined whether students could synthesize all of their conceptual understanding and procedural skills to finally solve the problem. ITS Module 1 is limited in improving student learning of frictional force and strengthening students' skills for knowledge synthesis.

The results of Figs. 6 and 8 show that ITS Module 2 significantly increased student learning gains for nearly all seven assessment questions, except question 7. As shown in Table 1, assessment question 7 also examined whether students could synthesize all conceptual understanding and procedural skills to finally solve the problem. This means that like ITS

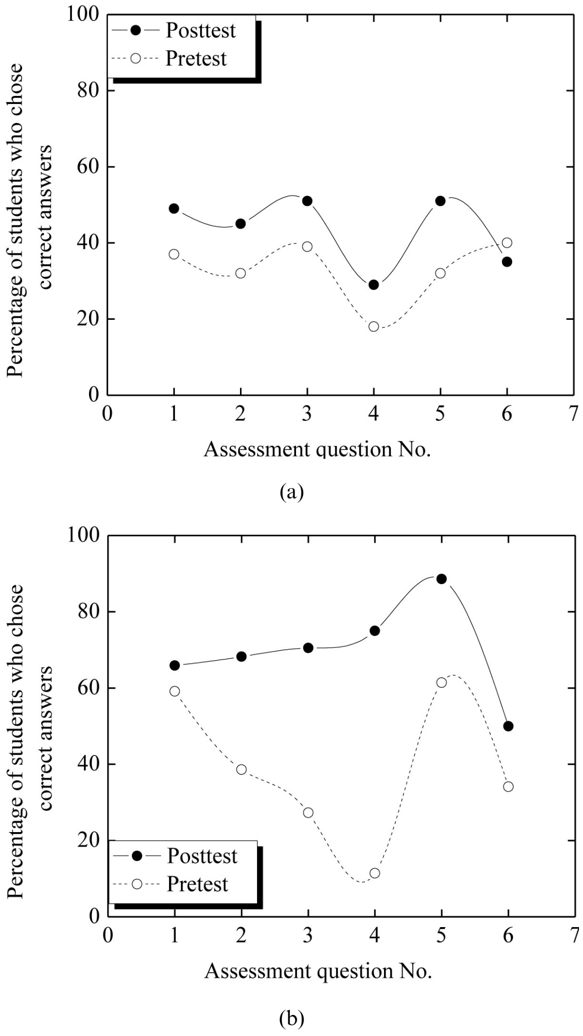


Fig. 7. Percentage of students who chose correct answers: (a) in the control semester when students did not use ITS Module 1, and (b) in the treatment semester when students used ITS Module 1.

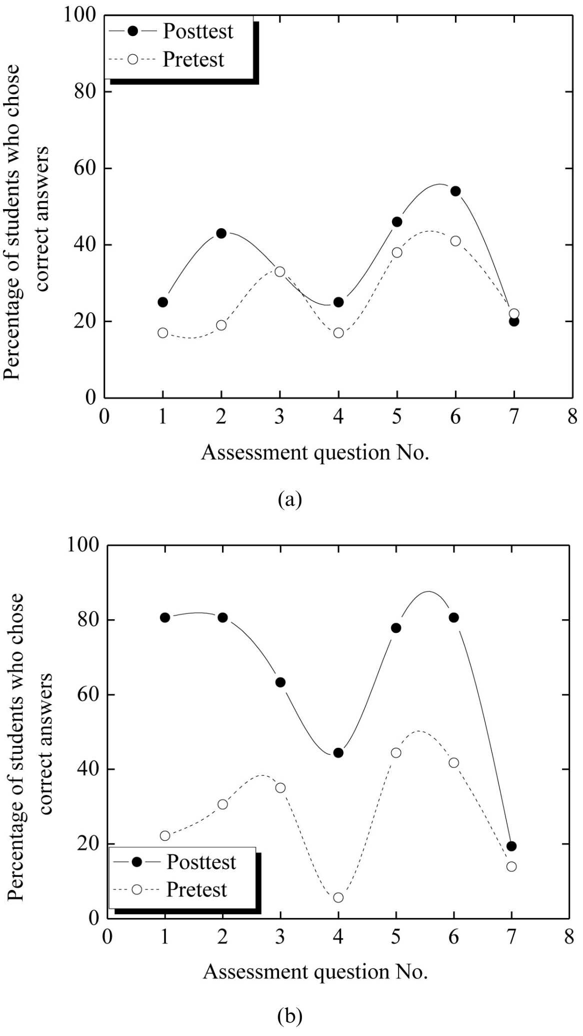


Fig. 8. Percentage of students who chose correct answers: (a) in the control semester when students did not use ITS Module 2, and (b) in the treatment semester when students used ITS Module 2.

Module 1, ITS Module 2 also has a limitation in enhancing students' skills for knowledge synthesis.

It must also be indicated that negative learning gains occurred in the control semester for assessment question No. 6 of ITS Module 1 (see Fig. 5) and assessment question No. 7 of ITS Module 2 (see Fig. 6). As described in the above paragraphs, both assessment questions required students to synthesize all of their conceptual understanding and procedural skills to finally solve the problem. Traditional lectures conducted in the control semester failed to improve student skills for knowledge synthesis in the present study.

4.2 Student evaluations

Table 5 shows the detailed student ratings for three Likert-type survey items listed in Table 2. From Table 5, 72.7% of students rated the overall quality of the ITS modules as high or very high, 72.8 % of students agreed or highly agreed that the ITS modules enhanced their conceptual understanding of dynamics problems, and 65.9% agreed or highly agreed that the ITS modules enhanced their procedural skills to solve dynamics problems. The mean values and the standard deviations of student ratings for three Likert-type survey items are: Item 1 (Mean = 3.91, SD = 0.88), Item 2 (Mean = 3.86, SD = 0.82), Item 3 (Mean = 3.73, SD = 1.09).

In students' responses to two open-ended questions regarding how the ITS modules enhanced their conceptual understanding and procedural skills, many students used the words "hints" and "step-by-step process" to describe their experiences. Representative student comments are listed in the following paragraphs.

Describe how the ITS modules enhanced conceptual understanding:

- "It provided an organization to look at the problem, see what concepts were involved, solve conceptually, and then plug in numbers."
- "It was a very good step-by-step learning system. It focused on basic concepts in detail."
- "I liked the immediate ability to get help (hints)."
- "I learned from the hints and the concepts explained more in-depth and visually."

Describe how the ITS modules enhanced procedural skills:

- "I really liked the ITS learning modules because it gave me the answers as I learned, so I truly better understood the problem solving process for the homework."
- "The program helped walking through step by step. It was nice having guided practice problems."
- "I appreciated that when I choose the wrong answer, the system told me that it was wrong. This helped me know what to do."
- "It guided me through and taught me the procedure."

5. Discussions of the present study

5.1 Implication of the present study

Both above-described quantitative and qualitative data show that the two ITS modules developed from the present study improved student learning of the Principle of Work and Energy in both particle and rigid-body dynamics. However, it was also found that both ITS modules were limited in their capacity to improve students' skills for knowledge synthesis to finally solve dynamics problems. The following paragraphs described two reasons why it is difficult to improve students' skills for knowledge synthesis.

First, knowledge synthesis is regarded as one of the highest-order problem-solving skills that a learner has [24–26]. In the well-known Bloom's taxonomy [27], a learner's cognitive learning domain is categorized at six levels: knowledge, comprehension, application, analysis, synthesis, and evaluation. The higher the cognitive learning level that a learner has, the stronger problem-solving skills that the learner has. Knowledge synthesis is listed at the fifth level in a learner's cognitive learning domain. To solve a complex dynamics problem, students must not only understand what dynamics principle(s) and associated equations should be used, why and how they are used, but also must be able to synthesize all conceptual understanding and procedural skills to finally reach a numerical solution to the problem. Knowledge synthesis has been presenting a great and intrinsic challenge for many engineering students, regardless of what educational/instructional technology is employed [28, 29].

Second, although research has found that intelligent tutoring systems help improve student learning

Table 5. Percent of students who rated three Likert-type survey items

	Rating				
Likert-type survey items	**1**	**2**	**3**	**4**	**5**
Item 1: I would like to rate the overall quality of the ITS modules as	2.3%	2.3%	22.7%	47.7%	25%
Item 2: The ITS modules enhanced my conceptual understanding of dynamics problems	0%	6.8%	20.5%	52.3%	20.5%
Item 3: The ITS modules enhanced my procedural skills to solve dynamics problems	4.5%	9.1%	20.5%	40.9%	25.0%

(such as [10, 30]) and that computer tutoring and human tutoring could be comparable in some cases [14, 15], we argue that intelligent tutoring systems cannot *completely* replace human tutors due to the level of intelligence and flexibility that human tutors can offer. This is especially true for students learning engineering subjects where technical problems are often complex and the complete mastery of engineering knowledge and skills require years of diligent effort to learn and years of professional practice in the engineering field.

The above discussions imply that intelligent tutoring systems should not be used to replace students' experiences with human instructors and tutors. In other words, intelligent tutoring systems should be used as a supplemental tool to enhance student learning, rather than a tool to replace human instructors.

5.2 Limitations of the present study

The present study has two primary limitations. First, only two ITS modules were developed in the present study, and the two ITS modules focus on the Principle of Work and Energy only. Of course, engineering dynamics covers many other topics such as Newton's Second Law, the Principle of Impulse and Momentum, and vibration. In future work, more ITS modules will be developed to cover other topics in engineering dynamics.

Second, the present study employed a quasi-experimental research method to quantify student learning outcomes. Participants of the present study were students who were enrolled in a dynamics course during either of two semesters at a public research institution in the USA. In future work, student participants would be randomly selected so as to accurately assess student learning outcomes through a true (rather than quasi) experimental research design method.

6. Conclusions

This paper has described two web-based interactive ITS modules that we developed for and implemented in an engineering dynamics course to help students learn how to apply the Principle of Work and Energy to solve particle and rigid-body dynamics problems. Two cohorts of engineering undergraduates who were enrolled in a dynamics course participated in the present study; one cohort participated during a control semester and the other during a treatment semester. The answers to the two research questions of the present study are summarized in the following paragraphs.

Research question No. 1: To what extent did the developed ITS modules help students learn how to apply the Principle of Work and Energy to solve particle and rigid-body dynamics problems? *Answer:* Based on the results of a quasi-experimental research design that involved a pretest and posttest in control and treatment semesters, the two ITS learning modules developed from the present study increased class-average student learning gains by 36.8% and 43.0%, respectively.

Research question No. 2: What were students' attitudes toward and experiences with the developed ITS modules? *Answer:* The results of an anonymous questionnaire survey show that a student had positive attitudes toward and experiences with the developed ITS modules. 72.8 % of students agreed or highly agreed that the ITS modules enhanced their conceptual understanding of dynamics problems. 65.9% agreed or highly agreed that the ITS modules enhanced their procedural skills to solve dynamics problems. Many students used the words "hints" and "step-by-step process" to describe how the ITS modules enhanced their conceptual understanding and procedural skills.

From the present study, we found that the two ITS modules, though effective, were limited in their capacity to improve students' skills for the knowledge synthesis that is required to solve dynamics problems. How to improve students' skills for knowledge synthesis remains a great challenge in the engineering education community. It is suggested that given their level of flexibility, intelligent tutoring systems be used as a supplemental tool for learning, rather than a tool to completely replace students' experiences with human instructors and human tutors.

References

1. R. C. Hibbeler, *Engineering mechanics dynamics* (13th edition), Pearson Prentice Hall, Upper Saddle River, NJ (2012).
2. M. A. Magill, Classroom models for illustrating dynamics principles, part I-particle kinematics and kinetics, *Proceeding of American Society of Engineering Education Annual Conference and Exposition,* Milwaukee, WI, June 15–18, 1997.
3. M. B. Rubin and E. Altus, An alternative method for teaching dynamics, *International Journal of Engineering Education*, **16**(5), 2000, pp. 447–456.
4. S. F. Barrett, E. W. LeFevre, J. W. Steadman, J. S. Tietjen, K. R. White and D. L. Whitman, *Using the Fundamentals of Engineering (FE) examination as an outcomes assessment tool*, National Council of Examiners for Engineering and Surveying, Seneca, SC (2010).
5. P. J. Cornwell, Dynamics evolution—change or design, *Proceedings of the 2000 ASEE Annual Conference & Exposition*, St. Louis, MO, June 18–21, 2000.
6. J. Njock-Libii, Using microsoft windows to compare the energy dissipated by old and new tennis balls, *Proceedings of the 2010 National Conference of the American Society for Engineering Education*, Louisville, KY, June 20–23, 2010.
7. K. J. Shryock, A. R. Srinivasa, and J. E. Froyd, Assessing first-year calculus knowledge and skills for a sophomore statics and dynamics course, *Proceedings of the 2011 ASEE Annual Conference & Exposition*, Vancouver, BC, Canada, June 26–29, 2011.
8. V. Aleven, B. M. McLaren, J. Sewall and K. R. Koedinger, A new paradigm for intelligent tutoring systems: Example-

tracing tutors, *International Journal of Artificial Intelligence in Education*, **19**(2), 2009, pp. 105–154.

9. A. C. Graesser, P. Chipman, B. Haynes and A. Olney, AutoTutor: An intelligent tutoring system with mixed-initiative dialogue, *IEEE Transactions on Education*, **48**(4), 2005, pp. 612–618.
10. S. Schiaffino, P. Garcia and A. Amandi, eTeacher: Providing personalized assistance to e-learning students, *Computers & Education*, **51**, 2008, pp. 1744–1754.
11. B. P. Butz, An intelligent tutoring system for circuit analysis, *IEEE Transactions on Education*, **49**(2), 2006, pp. 216–223.
12. M. Chi and K. VanLehn, Meta-cognitive strategy instruction in intelligent tutoring systems: How, when, and why, *Educational Technology & Society*, **13**(1), 2010, pp. 25–39.
13. K. R. Koedinger and J. R. Anderson, Intelligent tutoring goes to school in the big city, *International Journal of Artificial Intelligence in Education*, **8**(1), 1997, pp. 30–43.
14. D. C. Merrill, B. J. Reiser, M. Ranney and J. G. Trafton, Effective tutoring techniques: A comparison of human tutors and intelligent tutoring systems, *The Journal of the Learning Sciences*, **2**(3), 1992, pp. 277–305.
15. K. VanLehn, The relative effectiveness of human tutoring, intelligent tutoring systems, and other tutoring systems, *Educational Psychologist*, **46**(4), 2011, pp. 197–221.
16. B. Aberšek and V. Popov, Intelligent tutoring systems for training in design and manufacturing, *Advances in Engineering Software*, **35**(7), 2004, pp. 461–471.
17. A. A. Kassim, S. A. Kazi and S. Ranganath, A web-based intelligent learning environment for digital systems, *International Journal of Engineering Education*, **20**(1), 2004, pp. 13–23.
18. A. Keles, R. Ocak, A. Keles and A. Gulcu, ZOSMAT: Web-based intelligent tutoring system for teaching-learning process, *Expert Systems with Applications*, **36**(2), 2009, pp. 1229–1239.
19. C. K. Soh and A. Gupta, Intelligent interactive tutoring systems for engineering mechanics, *Journal of Professional Issues in Engineering Education and Practice*, **126**(4), 2000, pp. 166–173.
20. A. C. Graesser, K. VanLehn, C. P. Rosé, P. W. Jordan and D. Harter, Intelligent tutoring systems with conversational dialogue, *AI Magazine*, **22**(4), 2001, pp. 39–51.
21. J. Sweller, Cognitive load during problem solving: effects on learning, *Cognitive Science: A Multidisciplinary Journal*, **12**(2), 1988, pp. 257–285.
22. B. Johnson and L. Christensen, *Educational research: quantitative, qualitative, and mixed approaches,* Pearson, Boston, MA (2004).
23. R. R. Hake, Interactive-engagement vs. traditional methods: A six-thousand-student survey of mechanics test data for introductory physics courses, *American Journal of Physics*, **66**(1), 1998, pp. 64–74.
24. T. Litzinger, P. Van Meter, N. Kapli, S. Zappe and R. Toto, Translating education research into practice within an engineering education center: two examples related to problem solving, *International Journal of Engineering Education,* **26**(4), 2010, pp. 860–868.
25. R. E. Mayer, Cognitive, metacognitive, and motivational aspects of problem solving, *Instructional Science*, **26**(1–2), 1998, pp. 49–63.
26. R. E. Mayer, *Thinking, problem solving, cognition,* W. H. Freeman and Company, New York, NY (1992).
27. B. S. Bloom, M. D. Engelhart, E. J. Furst, W. H. Hill and D. R. Krathwohl, *Taxonomy of educational objectives: the classification of educational goals; Handbook I: Cognitive Domain,* Longmans, Green, New York, NY (1956).
28. E. Waller and M. H. Kaye, Teaching problem-solving skills to nuclear engineering students, *European Journal of Engineering Education*, **37**(4), 2012, pp. 331–342.
29. P. Gibbings and L. Brodie, Assessment strategy for an engineering problem-solving course, *International Journal of Engineering Education*, **24**(1), 2008, pp. 153–161.
30. A. Sarrafzadeh, S. Alexander, F. Dadgostar, C. Fan, and A. Bigdeli, "How do you know that I don't understand?" A look at the future of intelligent tutoring systems, *Computers in Human Behavior*, **24**(4), 2008, pp. 1342–1363.

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