Use of Warm Up Exercises in Just-in-Time Teaching to Determine Students Prior Knowledge and Misconceptions in Biology, Chemistry, and Physics

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Abstract: *We describe the use of web-based Warm Up exercises to reveal students prior knowledge and misconceptions in Biology, Chemistry, and Physics. This paper shows how the use of preparatory Warm Up exercises and analysis of student responses can uncover pre-existing knowledge and misconceptions, reinforce class content, and increase active learning .*

Manuscript:

Just-in-Time Teaching (JiTT) is a pedagogical strategy that uses the internet to enhance and extend classroom instruction. Developed at IUPUI (Indiana University Purdue University Indianapolis) and the United States Air Force Academy, JiTT is an established method that helps engage students in their work, and also has been shown to increase retention, process skills, and content knowledge in students studying sciences. JiTT methods are now used in over 50 institutions across the United States. Initial assessment results have been positive, including decreased attrition rates (reduced by 30-40% in several cases), increases in student attitudes and critical thinking, and improved student outcomes. More information about this method can be found in the recent book *Just-In-Time Teaching: Blending Active Learning with Web Technology* (Novak et. al 1999).

JiTT succeeds through a combination of high-tech and low-tech elements. On the high-tech side, the internet is used to deliver curricular materials - lecture outlines, pre- and post-class assignments - and to manage communications among faculty and students. On the low-tech side, an interactive classroom environment that emphasizes active and cooperative learning and student-student interactions decreases the use of traditional lecture in favor of problem-solving and small group work. This combination of high-tech and low-tech elements produces an educational setting that students find engaging and instructive, and is particularly valuable in large enrollment courses, for commuting or part-time students, and in any case in which a student's first allegiance is not necessarily to the course, but may be competing with the student s existing job, family, and personal responsibilities (Novak et. al 1999).

The fundamental idea behind JiTT is to establish a feedback loop between the Web and the classroom using a student s prior knowledge as part of the course structure. The JiTT system is based around web-based preparatory assignments called Warm Up exercises that are due electronically a few hours before class. We will show how we use Warm Up exercises as a foundation to base each classroom session not only on the content that the professor was planning to discuss on that day, but also to address the student s prior knowledge and misconceptions.

Prior Knowledge and Misconceptions

Prior knowledge can be defined as a combination of the learner's preexisting *attitudes*, *experiences*, and *knowledge* (NcREL, 1995). The importance of prior knowledge has been extensively reviewed (Bransford et al 1999) and can be summarized as follows (Roschelle 1995):

Educators often focus on the ideas that they want their audience to have. But research has shown that a learner's prior knowledge often confounds an educator's best efforts to deliver ideas accurately. A large body of findings shows that learning proceeds primarily from prior knowledge, and only secondarily from the presented materials. Neglect of prior knowledge can result in the audience learning something opposed to the educator's intentions, no matter how well those intentions are executed in an exhibit, book, or lecture.

Misconceptions, defined as incorrect interpretations or misunderstandings of an idea, concept, or process, are often a large part of students prior knowledge. Misconceptions can be categorized as follows, as described in Misconceptions as Barriers to Understanding Science (Committee on Undergraduate Science Education,1997):

- *Preconceived notions*: forming an opinion prior to actual knowledge or experience.
- *Non-scientific beliefs*: from religious or mythical teachings.
- *Conceptual misunderstandings*: incomplete or over-simplified knowledge from previous science courses.
- *Vernacular misconceptions*: uncertainty about differences between the popular vs. the scientific use of words like work or theory .
- *Factual misconceptions*: falsities learned at an earlier time and retained.

The most current research on student s prior knowledge and misunderstandings of science indicates that new concepts are best learned when teachers uncover and address pre-existing knowledge that their students bring with them (Branford et. al, 1999, 19). This paper will show how we use Warm Up exercises, to (1) identify student beliefs, misconceptions and prior knowledge, (2) synchronize the student responses with classroom instruction, and (3) provide classroom time to confront misconceptions. In doing so, we incorporate students prior knowledge as a foundation on which to construct further knowledge of the subject matter. We describe here the results for three courses at IUPUI: Biology N100, a large enrollment (>200 students / semester) course for non-science majors, Chemistry 105, a large enrollment (>300 students / semester) introductory course for science majors, and in Physics 151 and 152, two courses for science majors with an enrollment of >60 students each per semester. All of these courses are taught in a fixed-seat, lecture auditorium, but each has multiple interactive features as a result of Just in Time Teaching.

Warm Up exercises: The key to identifying prior knowledge and misconceptions

One of the goals of Just in Time Teaching is to address a student s prior knowledge as part of the course structure. Warm Ups are an ideal tool to assess prior knowledge and understanding (or misunderstanding) of a concept before the subject is presented in the classroom. Each week, 1 or 2 new Warm Up assignments, consisting of 3 questions each, is posted to the course website. Depending on the course, students have anywhere from 1 day (Physics) up to 3 days (Biology) to answer these preparatory questions. In all classes, Warm Up responses are due two hours before class time. Students are asked to do the assigned readings, as well as to look at the web links to lecture outlines and objectives for the upcoming week before answering the Warm Up questions. This compels the student to do the readings and look at the chapter material before answering the Warm Up questions, and has an important added benefit - students come to class having already read the material, increasing their participation in class discussions and problem-solving exercises. Students typically reveal, through writing the answer to the Warm Up question, ideas they bring to class from high school, from other college courses, from the media, as well as from explanations they generate based on what they read in the textbook.

Figure 1 shows a typical Warm Up exercise in Biology N100 (although in N100, these three questions were actually used in three different Warm Up exercises, and are grouped together only for the purpose of this paper). The first question was used as a Warm Up before discussing the scientific method, evolution and natural selection. The second question was used before a discussion of mitosis and cancer. The third question was used before a discussion of aerobic respiration. Figures 4 and 5, respectively, show examples of Warm Up questions and selected student responses in Physics and Chemistry. Many more Warm Up questions and information can be found at the WebScience project at IUPUI at http://webphysics.iupui.edu/webscience/webscience.html

A Warm Up question usually presents a situation that that students are likely to be **somewhat** familiar with, and requires students to speculate or develop a hypothesis before forming the answer. Warm Up exercises often ask students why? , and typically do not question students on direct factual information found in the textbook. Students generate answers to Warm Up questions based on both their prior knowledge of the subject as well as new information they learn from reading the textbook or lecture notes. To ease the pressure of submitting an answer that may be incomplete, underdeveloped, or just plain incorrect, full points are given to all students who respond on time - Warm Up responses are not graded initially as right or wrong. Students access the Warm Ups through the course web pages at their own pace, and submit them via the internet, where they are collected in a cgi-bin.

Warm Up responses: synchronizing student responses with classroom discussion

In many classroom settings, the professor is unaware of student misconceptions may bring to class with them, and begin a lecture or discussion with no knowledge of their student s understanding of the material. In Just-in-Time teaching, becoming aware of student s pre-existing knowledge is a goal of the method, made possible by analysis of Warm Up questions. To make the best instructional use of the students responses, we set aside an hour or so before class to collect student responses from the cgi-bin and read through the responses.

While reading student Warm Up responses, it is usually evident that the students are clear about some points and unclear about other points addressed in the Warm Up questions. Frequently, serious misconceptions are revealed in the students written answers to the Warm Up question. This is true even though the students have done the readings for that day, have had access to information available on the internet, and may have already introduced to this subject in a previous high school or college course. Examples of specific student Warm Up responses and misconceptions are shown in the next section.

Once we identify a few points that, based on student responses, need to be further clarified in that day s class, we determine where to adjust the upcoming classroom lesson in response to the student submissions Just in Time , and decide how much time to devote to a concept that was to be discussed that day. Should the majority of the class appear to be confused on a particular Warm Up question, more time can be planned to clarify this concept in class. Should the majority of the class appear to understand a concept, more time can be spent in class discussing other concepts.

Just before class time, we select two or three Warm Up responses for each question, and copy and paste these responses into a page of comments. This page can be uploaded immediately to the course web page, if the instructor uses the web in class, or a transparency can be made to be shown in class. N100 uses the web live in class, and Chemistry C105 and Physics 152 / 251 use transparencies. At the appropriate time in class, student responses to the Warm Up questions are shown and discussed, with a correction of misconceptions further reinforced by in-class group work (Marrs et al., in preparation, JiTT improves Student Study Skills). Students frequently report that they benefit from going over the sample Warm Up responses in class, and are usually pleased to see their answer, identified by nickname, presented to the class. As a result, students participate in a class that is based on prior knowledge, while still including all the content the faculty member was planning for that day s discussion.

Assessment: Analyzing Warm Ups for Accuracy Using a Scoring Rubric

We often find it useful to do a quantitative analysis of Warm Up responses. We do this to determine how well the class as a whole was able to answer a Warm Up question, to uncover common misconceptions students might have, to determine how much students used resources available to them, and even to assess how well a particular Warm Up question was constructed. We have found a scoring rubric to be helpful in doing this quantitative analysis. This scoring rubric is shown in **Figure 2**. As this figure indicates, student responses to Warm Up questions tend to fall into one of four categories.

As mentioned in the previous section, the students receive full credit for the Warm Up assignment just for answering on time, thus this scoring rubric is not used to grade the students. Rather, this rubric is helpful to the faculty member prior to class in determining **how much instructional time** should be devoted to a particular topic, based on the overall percentages of students who answer at each of the 4 levels. It is also useful after the class, when additional time looking over responses may be useful for further analysis.

At the first level, the student does not really try to answer the Warm Up question, either due to a fear of giving an incorrect answer (even though there is no penalty for guessing), a genuine confusion on where to begin answering, or perhaps just because they are not putting in the effort to think about the question and put forth an explanation. In the second category, minimal accurate prior knowledge the students ventures an answer, but the answer is clearly incorrect; the student does not show evidence of having read the reading assignment, and they may reveal obvious misconceptions about the concept. In the third category, students give an answer that is almost there — they attempt to use terminology from the readings, use logic or definitions in answering the question, and are at least partially correct, yet they still show an incomplete knowledge of the answer to the question. In the fourth category, the student gives a complete and thorough answer, using terminology from the readings or lecture notes, and perhaps even consulting sources on the internet to quote more information.

A specific example is shown in **Figure 3**, an analysis of student responses to the question Why do chemotherapy drugs make a person s hair fall out? . In writing this question, we were looking for the students to make connections between mitosis (the subject of the week, discussed in detail in the assigned readings), cancer (uncontrolled mitosis, discussed in a box essay in the assigned readings and a subject that most students have some prior knowledge of) and chemotherapy (drugs that kill any actively dividing cells, including cancer cells; a topic not discussed in the assigned reading).

Most people are familiar with the concept of hair loss following chemotherapy. Hair loss is one of the most visible effects of chemotherapy, but many tissues are affected (lining of mouth and digestive system, sperm production, etc). While most people are aware that chemotherapy causes a person to lose their hair, and bring that prior knowledge to class with them, they often do not realize why this is so.

As shown in **Figure 3**, only a small percentage of students (3%) had no explanation to offer for this question — just about everyone ventured some sort of explanation. However, almost half the class (47%) answered in the second category, revealing many misconceptions and interesting 'hypotheses' about why chemotherapy drugs cause hair to fall out. Clearly, most students were not making the connection that interruption of mitosis (the topic of the week) had a very important role to play in trying to stop growth of cancer cells, and instead cited misconceptions such as something special about cells producing hair, or hair loss just being a coincidence of chemotherapy.

29% of students gave answers that were nearly complete, but did not mention mitosis or DNA replication in their answer, omitting an important part of how these drugs work, and more importantly, demonstrating that they did not make the connection that mitosis was involved. Finally, 21% of students gave complete answers, mentioning cell division, mitosis, DNA replication, with some even citing information they learned from going to other sources on the web.

Figure 4 shows the analysis of a question in Chemistry entitled Warming Up to States of Matter . While the states of matter (solid, liquid, gas, and plasma) are taught to students at an early age, and are a part of the required readings for this question, many students do not how to interpret visual information in light of verbal information they have already read. The intention of this warm-up was to probe whether students understand the characteristics of the states of matter at a conceptual level. This Warm Up was intended to be used very early in the semester, and was designed to be a confidence builder . We felt that a beginning chemistry student could analyze the picture in the following way:

1) The picture shows organization into a definite structure, which means this must represent a solid state of matter.
2) There are 14 of each type of circle in the picture, which implies that the material is composed of two species in a 1:1 ratio.

3) The alternating structure of the circles would be characteristic of the packing of cations and anions in a crystal of a simple salt like NaCl.

As shown in **Figure 4**, misconceptions include the following: (1) The substance is a gas or a liquid, usually assumed because there is space between the circles in the picture (over 33% of the class answered this way). (2) The particles are not bonded to each other (many students expect to see lines drawn between any two things that are bonded to each other). (3) The picture represents an atom of an element (10% of the students guessed that the circles represented protons and electrons..

Finally, an example of a Physics Warm Up is shown in **Figure 5**. This question is one of three in a WarmUp exercise introducing the ideas of electric potential and electric potential energy. As in the other two examples, only a small percentage of students answered at level 1; almost all have some idea how to answer based either on the reading or on their preconceived notions. Level 2 was again the most common, with 57% of the students answering at that level. The numbers of students answering at levels 3 and 4 were approximately equal: 22% and 21% respectively.

Most students in this class are science or engineering majors, and have had a long exposure to the idea of potential energy. However, most of this experience has been with mechanical systems (e.g., potential energy stored in a spring), which is easy to visualize. Electric potential is a phrase students are less likely to be familiar with, although it refers to voltage, a concept most students are familiar with from their experience with batteries and household power. Even though most of the students are familiar with both ideas, they are often confused about the relation between them. Part c of the response at level three (It could be the electric potential vs. distance for a positive or a negative charge, but depends on the coordination of the electric field) is a good indication of this. The student s answer has been correct up to this point (dealing with potential energy), but then confusion sets in when the student is asked to deal with the potential, which is defined for a single particle rather than for a pair.

Many students are also confused by cases in which the potential or potential energy is negative. The first response in level two is a good example. The student has understood that the potential energy is inversely proportional to distance, but has not considered the possibility of a negative function which decreases in magnitude and hence becomes larger as the distance increases.

Taken together, we see from analyzing student responses to Warm Up exercises (**Table 1**) that the largest response category is Level 2 — most students show minimal accurate prior knowledge, even after doing the readings for the upcoming class. When asked directly, we found that an average of 70% of the students did the required reading before answering the Warm Ups (Marrs et al., in preparation, JiTT improves Student Study Skills). However, since we become aware of these misconceptions by looking at the Warm Up responses before class, we are able to address, discuss, and in large part replace, these misconceptions with accurate knowledge in that day s class period. This is further enhanced by alternating traditional lecture portions of the class with in-class cooperative learning exercises or problem solving, and direct discussion of Warm Up responses. We are currently testing the effect of Check Up questions, given as part of a subsequent Warm Up (after class) or as part of a cooperative learning assignment in class, and preliminary results show a significant reduction of misconceptions after students have had both a Warm Up question and a class discussion on the topic (Marrs et al., in preparation, JiTT improves Student Study Skills).

Discussion:

Just in Time Teaching is an innovative approach that allows students to become active participants in their learning before, during, and after class. As we have shown in this paper, Warm Up exercises guide the learning process, addressing several pedagogical goals. First, they require a student to do preparatory work, readings the material prior to class, and writing about what they already know about a topic to activate their prior knowledge. Second, they require the faculty member become aware of the students' prior knowledge about the material that will be presented in class. Analysis of Warm Up responses can be an effective way to assess student knowledge, providing a "snapshot" of students' content knowledge just before it is needed. Finally, addressing this prior knowledge in class as part of the class discussion increases a student's comprehension of that day's material. This method is constructivist; encouraging students to relate what is being learned with what they already know, via the faculty (Leonard 2000). It also fosters a feedback cycle of preparation and active involvement recommended by established research in science education (Bransford, 2000, Lord, 1998, Leonard 2000, Klionski, 2002). While this method requires an extra input of time from a faculty member or student grader, we have found it to be more than worth the additional effort due to its positive effects teaching and learning.

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Figures for JCST Paper:

Opening Photo: N100 Students)

(Figure 1: Warm Up exercise with text boxes and submit button)
Figure 1 shows an example of a warm up exercise

- What is the difference between a theory and a belief?
- Why do chemotherapy drugs make a person s hair fall out?
- Why are people who are anemic (have low levels of functioning red blood cells) feel tired and weak?

Figure 2: Scoring Rubric to Evaluate Student s Prior Knowledge
Adapted from de Caprariis, Barman, and Magee. 2001

1. Student says he / she does not know how to answer the Warm Up question.

2. Student tries to answer the Warm Up question but shows minimal accurate prior knlwledge knowledge to assist in answering. Student does not use any information from the text or lecture notes to answer the question. Student may reveal misconceptions about concepts. (Incorrect answer)

3. Student shows some prior knowledge and may use terminology to answer the Warm Up question. Student does not use appropriate information from the text or lecture notes to answer the question. (May be partially correct but still incomplete).

4. Student answers the Warm Up question correctly and completely. Student incorporates information from the text or class notes into the answer. Student may look for answer outside the class (web, etc).

Table 1: Analysis of Student Warm Up responses

	Biology	Chemistry	Physics
Level 1	3.1 % (6 responses)	3.8 % (11 responses)	4.7% (2 responses)
Level 2	47.1% (83 responses)	56.7% (162 responses)	63.8% (26 responses)
Level 3	28.8% (51 responses)	18.6% (58 responses)	24.2% (10 responses)
Level 4	21.0% (37 responses)	20.9% (60 responses)	7.3% (3 responses)
n =	(176 responses)	(286 responses)	(41 responses)

Figure 3: Analysis of a Warm Up Question on Mitosis: Sample Student Responses.
Scoring (1-4) is based on a rubric to determine patterns of student responses.
6 responses of 176 are shown. These answers were shown in class.

QUESTION = Why do you think chemotherapy drugs, which are given to fight cancer, cause a person's hair to fall out? Please read the notes on mitosis before answering the question.

Level 1: Student says he / she does not know how to answer the Warm Up question.

> I know that the drugs do this, but I don't have the slightest idea why. There is probably a very simple explanation for this that I am looking over.

(**3%** of students answered in this category for this particular question)

Level 2: Student tries to answer the Warm Up question but shows minimal accurate prior knowledge to assist in answering. Student does not use information from the text or lecture notes to answer the question. Student may reveal misconceptions about concepts. (Incorrect answer)

> I think it is because the drugs are trying to kill all of the bad cells and hair is only dead cells, so the drugs just see hair as bad cells and gets rid of them.
>
> Causes your the cells in your hair to age rapidly???
>
> I think that the chemicals, or whatever it is that kills the cancer, just happen to affect hair cells, causing them to die and having the hair fall out.

(**47%** of students answered in this category for this particular question)

Level 3: Student shows a moderate amount of accurate prior knowledge and may use terminology to answer the Warm Up question. Student does not use appropriate information from the text or lecture notes to answer the question. (Partially correct but still incomplete).

> The chemotherapy drugs used to fight cancer attempt to kill off the living cancer cells. Hair cells are not nearly as hard to kill as cancer cells and unfortunately the drugs can not be centered only on the cancer cells. This results in the killing off of many cells with the ultimate goal of killing the cancer cells in mind.

(**29%** of students answered in this category for this particular question)

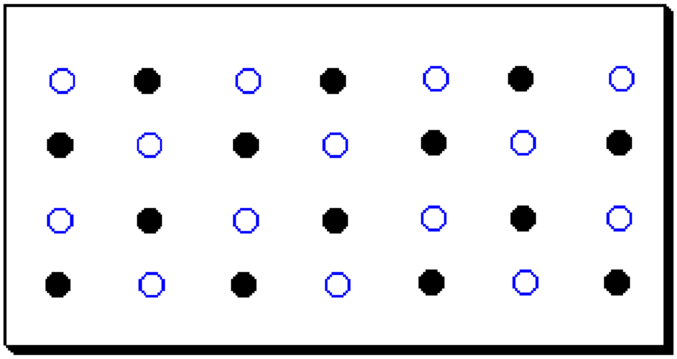
Level 4: Student answers the Warm Up question correctly and completely. Student incorporates information from the text or class notes into the answer. Student may look for answer outside the class (web, etc).

> Ok, I was able to find an answer to this one :) Chemotherapy = treatment of disease with chemicals or drugs; the term most often refers to treatment of cancer. Traditional cancer chemotherapy poisons all body cells to some extent, but particularly targets rapidly dividing cells such as cancer cells. Its effect on other rapidly dividing cells (hair follicles, cells lining the stomach, and red blood cells) accounts for some of the common side effects.

(**21%** of students answered in this category for this particular question)

Figure 4: Analysis of a Warm Up Question in Chemistry on States of Matter: Sample Student Responses. 6 responses of 176 are shown.
Scoring (1-4) is based on a rubric to determine patterns of student responses.

QUESTION: This picture depicts matter at the submicroscopic level. Describe what you see and take a guess as to what the identity of the substance might be.



Level 1: (Incorrect and incomplete)

"I see a whole lot of dots. I'm guessing that they are supposed to represent atoms."

(**3.8%** of students answered in this category for this particular question)

Level 2: (Minimal accurate prior knowledge, incorrect answer)

"I see two different types of particles evenly spaced and equal in number (14 black, 14 blue). The particles are well spaced out so I would guess the substance to be a gas. The substance is a gas composed of 2 elements that are in an equal ratio."

"I see 14 circles, and 14 dots. But I think the circles are electrons, and the dots are protons. So I think the Identity of the substance is Nickel. Because 14+14 is 28 and Nickel's atomic number is 28."

"I see a black element with 4 blue elements surrounding it. The structure could make me come to the conclusion that substance is Methane CH4."

(**66%** of students answered in this category for this particular question)

Level 3: (Moderate amount of accurate prior knowledge and use of terminology; partially correct but still incomplete).

"I see a group of evenly spaced, alternating black and white dots. It could be any mixture which is composed of two elements in equal proportions."

After reading Chapter 1 in the book I would guess that the substance is water in the form of a solid because the atoms are in order. However, I could be wrong because I think the atoms in a solid might be closer together.

(**18.5%** of students answered in this category for this particular question)

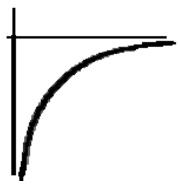
Level 4 Student answers the Warm Up question correctly and completely).

"I see white dots (with blue outlines) and black dots of approx. the same sizes organized in a predictible, patternistic manner and in 1:1 ratio.The dots are arranged in diagonal columns and alternate between columns of white to black dots. The highly oranized fashion of this model suggests a solid and more specifically a crystal ex: NaCl"

(**21%** of students answered in this category for this particular question)

Figure 5: Analysis of a Warm Up Question in Physics on States of Matter: Sample Student Responses. 6 responses of 176 are shown.
Scoring (1-4) is based on a rubric to determine patterns of student responses.

QUESTION: Consider the graph below. This could be the graph of gravitational potential energy vs. radius of orbit for a satellite orbiting the Earth. Could it also represent the potential energy for a positive charge as a function of radius near another positive charge? How about the potential energy for a negative charge as a function of radius near a positive charge? Could it be the electric potential vs. distance for a positive or negative charge? Please explain what this could or could not be and why.



Level 1: (Incorrect and incomplete)

"I am not too sure how to answer graphs for the positive and negative charges."

(**5%** of students answered in this category for this particular question)

Level 2: (Minimal accurate prior knowledge, incorrect answer)

"This can not be the graph of any of these, as they would all produce a graph where potential decreases with increasing distance (or radius)."

The graph becomes less negative for a larger R. This is the case for one positive and one negative charge. if both charges were positive it would cause the PE to become less positive for a larger R.

(**56.6%** of students answered in this category for this particular question)

Level 3: (Moderate amount of accurate prior knowledge and terminology, but still incomplete).

"It could not be electrical the potential energy for a positive charge as a function of radius near another positive charge, because as radius increases the electric field between them do positive Work and hence Potential energy is decreased.

"It could be the potential energy for a negative charge as a function of radius near a positive charge, because as radius increases the electric field in between do negative work so potential energy increases.

(**22%** of students answered in this category for this particular question)

Level 4 Student answers the Warm Up question correctly and completely).

"It cannot be the electrical potential energy for a positive charge as a function of radius near another positive charge because the electrical potential energy should be positive and as the radius increase the electrical potential energy will decrease."

"It can be the graph of potential energy for a negative charge as a function of radius near a positive charge because as the radius increase the electrical potential energy will decrease(less negative).

"It can be the graph of electric potential vs. distance a negative charge because as the radius increase the electric potential will increase(less negative).

(**21%** of students answered in this category for this particular question)

Just-in-Time-Teaching (JiTT) Improves Students' Performance in Classes - My adaptation of JiTT in 4 Geography Courses. Article (PDF Available) in Journal of Geoscience Education 56(2) Â· December 2007 with 133 Reads. DOI: 10.5408/1089-9995-56.2.166.Â Web-Based Warm Up Exercises in Just-in-Time Teaching-Determining Students' Prior Knowledge and Misconceptions in Biology, Chemistry, and Physics. Jan 2003. J Coll Sci Teach.