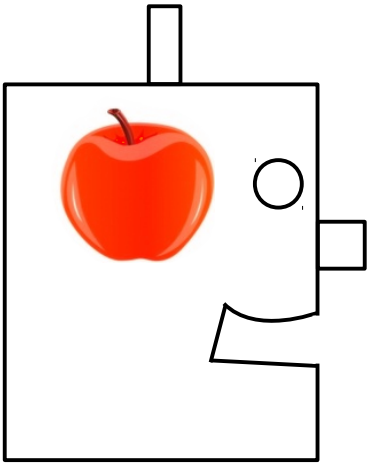
The Conventional Teaching Process Compared to the New Robot TA (Teaching Assistant) Teaching Process



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Feedback Response Times in Education have Improved Little in the Past 100 Years

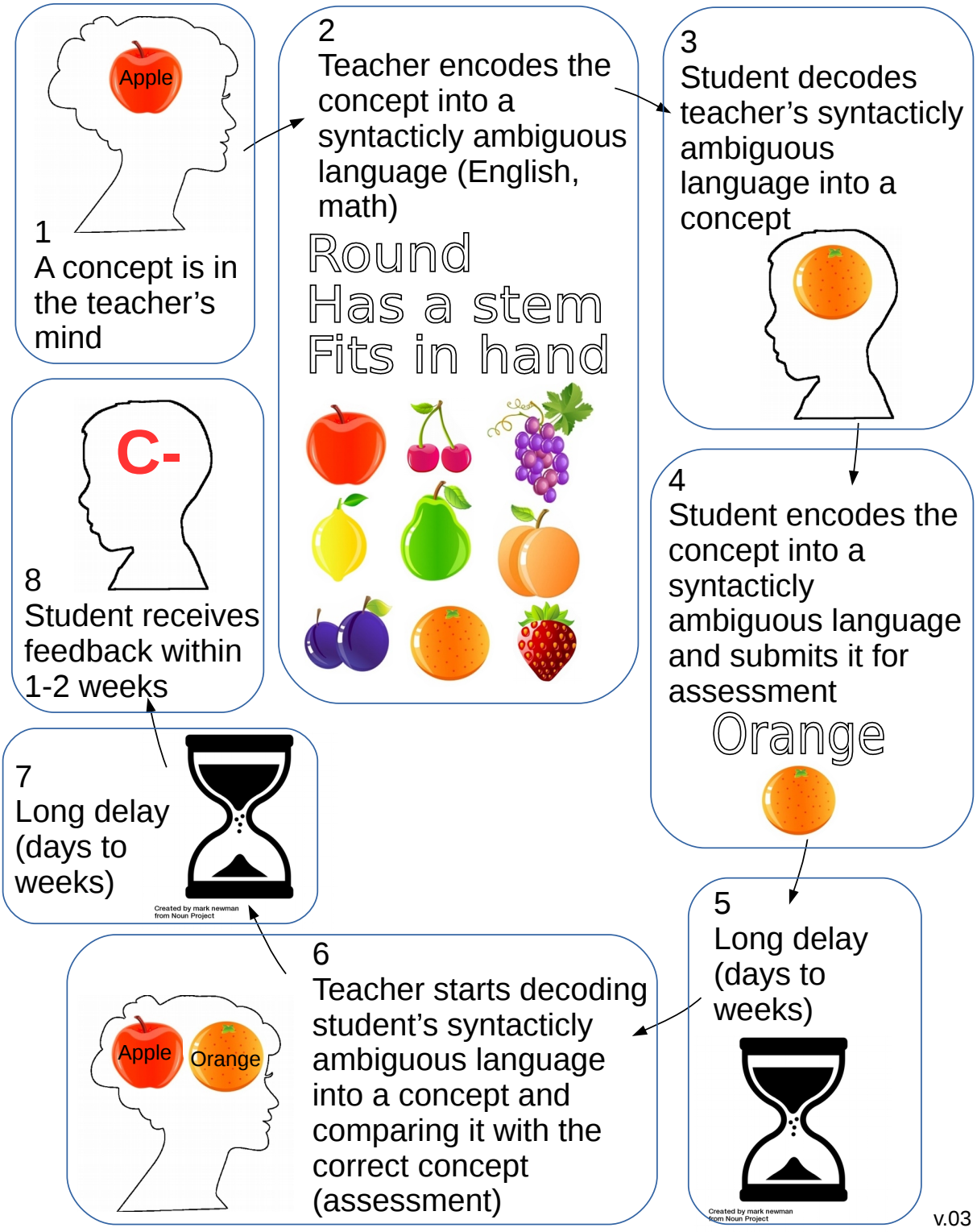
Response time in general is a large and growing area of competition. Ambulance companies, taxi companies, package delivery companies, online stores, call centers, pharmacies, etc. all compete on response time. Each of these organizations heavily utilize technology to reduce response times. As technology evolves, it makes achieving ever shorter response times possible.

For example, before automobiles became widely used, the standard process for obtaining emergency medical assistance consisted of using a horse to travel to a doctor and bringing them to the injured person. The response time was typically measured in hours. Today, a person who breaks their leg calls 911 on their cellphone, and an ambulance usually arrives within 10 minutes.

Response time in teaching is the time it takes a student to receive feedback on their work from the time it was submitted. Despite extensive advances in technology, the teaching process has changed very little in the past 100 years, and therefore feedback response times are still measured in weeks.

Using Robot Teaching Assistant (TA) technology in education makes it possible to radically reduce feedback response times while significantly increasing the quality of this feedback. The following paper compares the conventional teaching process to the new robot TA teaching process in order to explain the latter's advantages.

Fig. 1: Conventional Teaching Process



1 Fig. 1: The Conventional Teaching Process (Feedback Response Times Measured In Weeks)

1.1 Step 1-1: A Concept is in the Teacher's Mind

As Jeff Bezos (the CEO of Amazon) has said, "You can explain things to people, but you can't understand things to people." If a concept in a teacher’s mind could be directly copied into a student’s mind, there would be no need for teaching. Since copying concepts from one mind to another is not possible yet, the concept must be encoded into a language in order to be communicated outside of the teacher’s mind. In figure 1, the concept the teacher wants to communicate to a student is that of an apple.

1.2 Step 1-2: Teacher Encodes the Concept into a Syntacticly Ambiguous Language

All natural languages, such as English, French, and German, are syntacticly ambiguous. For example, the sentence “The girl saw the boy with the telescope.” has two meanings.

Linear mathematics notation is also syntacticly ambiguous. For example, 48/2(9+3) evaluates to 288 or 2 depending depending upon whether the expression is interpreted as meaning (48/2)(9+3) or as 48/(2(9+3)). Another example is -2*2 which evaluates to -4 or 4 depending upon whether the expression is interpreted as meaning -(2^2) or as (-2)^2.

The teacher is using English to communicate the concept of an apple to the student by stating some attributes an apple has. The attributes "round", "has a stem", and "fits in hand" all apply to an apple. However, they also apply to other fruit such as an orange, a pear, and a grape.

The ambiguity present in the encoding could be reduced if the teacher was able to check it for defects before it was given to the student. However, in the conventional teaching process this technique is usually too expensive to utilize.

1.3 Step 1-3: Student Decodes Teacher's Syntacticly Ambiguous Language into a Concept

The ambiguous nature of the communication has made it possible for the student to grasp the wrong concept, in this case an orange.

1.4 Step 1-4: Student Encodes the Concept into a Syntacticly Ambiguous Language and Submits it for Assessment

Having the student use a syntacticly ambiguous language to communicate their grasp of the concept to the teacher provides another opportunity to introduce errors into the learning process.

1.5 Step 1-5: Long Delay (Days to Weeks)

From the time a student submits their work for assessment to the time the teacher starts assessing it, days or weeks may have passed. Reasons for this delay include:

1) It is easier for a teacher to assess all student submissions for a given assignment close in time to each other than it is to assess them spread out in time. Therefore, a teacher will often wait to begin assessing an assignment until most of its submissions have been received.
2) Manual assessment is often tedious, boring, and depressing. The depressing aspect is often caused by the realization that many student did not grasp the concepts being taught very well. Since it is human nature to put off doing unpleasant things, the teacher often delays assessing an assignment for days or weeks.
3) There are usually no serious consequences for providing the results of assessment to students in a timely manner. Therefore, it is easy for a teacher to preempt the assessment of an assignment when events that are perceived to have higher priority occur.

1.6 Step 1-6 Manual Assessment

Manually assessment of student has the following weaknesses:

1) It is during the assessment of an assignment that the teacher receives feedback on how effective their teaching of a concept was. Days or weeks may have elapsed from the time the teaching of a concept occurred to the time feedback was received on the teaching's effectiveness. The longer this feedback delay is, the less likely it will be used to improve the teaching process.
2) During the time delay shown in Step 1-5, the teaching of many other concepts is likely to have occurred. Therefore, the teacher must make an effort to focus on the older concept so the more recently taught concepts do not mix with them during the assessment process.
3) Since the student's work is encoded in a syntacticly ambiguous language, the teacher will need to expend a significant amount of energy trying to identify the concepts the student is attempting to communicate. There are

four possibilities in this step:

a) The student grasped an incorrect concept, and encoded it clearly enough to identify it as incorrect.

b) The student grasped the correct concept, and encoded it clearly enough to identify it as correct.

c) The student grasped the correct concept, but encoded it unclearly so there is doubt as to whether they grasped the correct concept or not.

d) The student grasped an incorrect concept, and encoded it unclearly so there is doubt as to whether they grasped the correct concept or not.

Possibilities 1 and 2 are easy to assess while possibilities 3 and 4 are difficult to assess due to the ambiguity of their their unclear encoding.

4) In the conventional teaching process, human teachers often become tired, sick, distracted, rushed, etc. while assessing student work, and this can adversely affect the quality of the assessment. Assessing an assignment is similar to shooting a scene in a movie, except the actor (teacher) only gets one take for each scene.

1.7 Step 1-7 Long Delay (Days to Weeks)

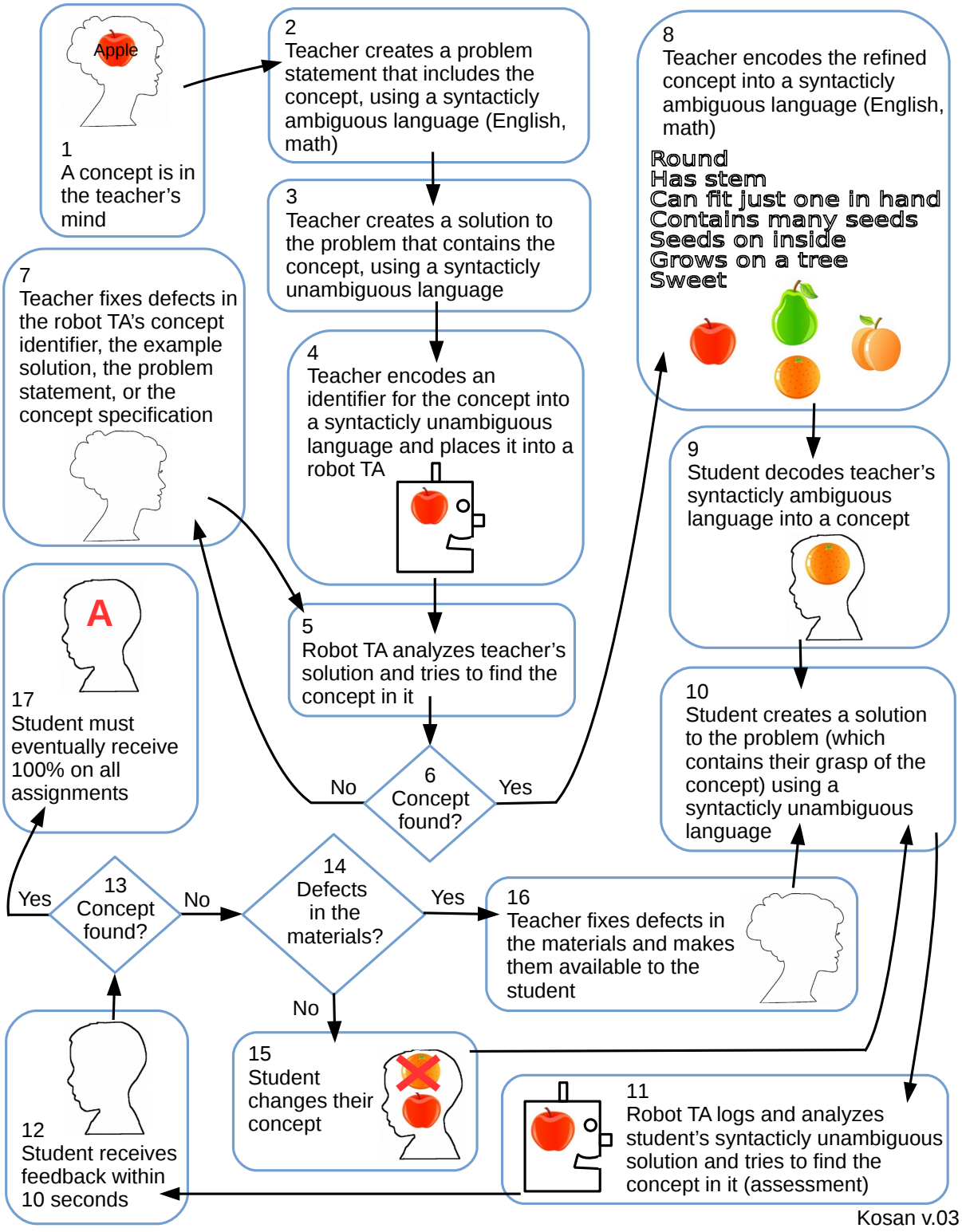
This delay consists of the time the teacher spends assessing all the submitted work for a given assignment along with the time it takes to communicate the results of the assessment back to the students. Even if a given student's work was the first to be assessed, they still will not receive feedback on it until the assessment of all the work the other students submitted is completed.

1.8 Step 1-8 Student Receives Feedback Within 1-2 Weeks

From the time a student was first taught a given concept to the time they receive feedback on their grasp of it, one to two weeks could easily have passed. During this time the student would likely have been taught numerous more advanced concepts that depend on correctly grasping the given one.

If the feedback indicated the student did not grasp the given concept correctly, they usually have little or no opportunity to correct the error because most of their time is being devoted to learning the more advanced concepts.

Figure 2: Robot Teaching Assistant Teaching Process



2 Fig. 2: Robot TA Teaching Process (Feedback Response Times Measured in Seconds)

2.1 Step 2-1: A Concept is in the Teacher's Mind

This step is similar to Step 1-1 except the clarity of the concept will likely be much greater than in the traditional teaching process because using robot TAs teaches a teacher how to think more clearly.

2.2 Step 2-2: Teacher Creates a Problem Statement that Includes the Concept, Using a Syntacticly Ambiguous Language (English, math)

In the conventional teaching process, the teacher usually creates the teaching materials first and the assessment problems second. In the robot TA teaching process, the assessment problems are created first because problems provide the foundation for three low-delay feedback loops:

1) The teacher iteratively refining the assessment materials, before they are given to the student, until the robot TA indicates they have achieved the desired level of refinement.
2) The student iteratively creating a problem solution until the robot TA indicates it contains the correct concepts.
3) The teacher iteratively refining the assessment materials, after a student has located an error in them, until the robot TA indicates they have achieved the desired level of refinement.

The current version of the robot TA teaching process uses a syntacticly ambiguous language in this step because they are easier to work with. More advanced versions of the robot TA teaching process may use a syntacticly unambiguous language in this step in the future.

2.3 Step 2-3: Teacher Creates a Solution to the Problem that Contains the Concept, Using a Syntacticly Unambiguous Language

In order to create a solution to the problem that contains the concept, in a syntacticly unambiguous language, the teacher must clearly grasp the concept. If the teacher does not yet clearly grasp the concept (which is likely), the process of encoding it into a syntacticly unambiguous language will help clarify it.

While the nature of syntacticly unambiguous languages is beyond the scope of this document, it does use one called a "flowchart" in figures 1 and 2. Flowcharts describe the steps in a process. The blue boxes and diamonds represent concepts. A diamond represents a type of concept that is a decision. The arrows between the boxes and diamonds represent the relation of sequence that is between these concepts.

2.4 Step 2-4: Teacher Encodes an Identifier for the Concept into a Syntacticly Unambiguous Language and Places it into a Robot TA

Most robots don't have common sense, therefore they can't be "taught" using syntacticly ambiguous natural languages such as English. Syntacticly unambiguous languages were developed in the 20th century in order to overcome the problems caused by the syntactic ambiguity of natural languages. In this step, the teacher encodes an identifier for the concept into a syntacticly unambiguous language and places it into the robot.

An example of a concept identifier is one that looks for decisions in a flowchart by trying to identify diamonds that may be in it. A more sophisticated concept identifier may look for a diamond that was directly related to another diamond with a sequence arrow (Step 2 has one instance of this concept). An even more sophisticated concept identifier may look for loops in a flowchart (which Step 2 has three instances of).

2.5 Step 2-5: Robot TA Analyzes Teacher's Solution and Tries to Find the Concept in it

This step is simpler than it may seem, because most of the hard work of creating a syntacticly unambiguous expression has already been done in steps 2-3 and 2-4. In this step, the robot very quickly (in well under a second) searches through the solution in order to determine if the concept is present.

2.6 Step 2-6: Concept found?

Sometimes a teacher wants to make sure a concept that should be present in a solution is actually present. Sometimes they want to make sure a concept that should not be present in a solution (perhaps a pineapple) is indeed not present. In this example, the robot TA has been told to look for a concept (an apple) that should be present.

If the robot TA finds the concept, it indicates PASS, and if it does not find the concept, it indicates FAIL. Since the robot was looking at the teacher's solution, it should have found the concept. If it does not find the concept, one or more defects are present that need to be corrected in step 2-7. If it does find the concept, the teacher can move on to creating the materials that will be used to teach the concept in step 2-8.

2.7 Step 2-7: Teacher Fixes Defects in the Educational Materials

If this step has been reached, there are one or more defects present in the following items:

1) Robot TA's concept identifier.

2) Example solution.

3) Problem statement.

4) Concept specification.

The teacher will cycle through steps 2-5, 2-6, and 2-7 until the robot TA identifies the concept in the solution, and the teacher is satisfied with the quality of these four items.

2.8 Step 2-8: Teacher Encodes the Refined concept into a Syntacticly Ambiguous Language (English, math)

This step is similar to the analogous step in Figure 1. However, the detail and clarity of the concept should be significantly higher because it was likely refined during the process of "teaching" the robot TA how to identify it.

The current version of the robot TA teaching process uses a syntacticly ambiguous language in this step because they are easier to work with. More advanced versions of the robot TA teaching process may use a syntacticly unambiguous language in this step in the future.

2.9 Step 2-9: Student Decodes Teacher's Syntacticly Ambiguous Language into a Concept

This step is similar to the analogous step in Figure 1, but the student should be more likely to grasp the correct concept due to its increased level of detail and clarity. Also, the teacher should be much better prepared to answer questions about the concept because they have created a solution that uses it, and the robot TA is a much more demanding "student" than human students are.

As mentioned in a previous section, robot TAs don't have common sense, so concepts need to be "explained" to them in exacting detail. Therefore, if a teacher succeeds in getting a robot TA to identify a given concept, they will be able to answer questions about the concept at almost any level of detail that the student desires.

2.10 Step 2-10: Student Creates a Solution to the Problem Using a Syntacticly Unambiguous Language

As with the teacher in step 2-3, having the student encode their grasp of the concept into a syntactically unambiguous language will automatically help clarify the concept.

There are a large number of syntactically unambiguous languages in existence, and new ones can be created for special purposes. An increase in use of robot TAs will be accompanied by the creation of numerous unambiguous language that will be specifically designed for the needs of education.

2.11 Robot TA Records and Analyzes Student's Solution and Tries to Find the Concept in it

In step 2-5, the concept identifier that was placed in the robot TA was used to try find the concept in the teacher's solution. In this step, the same identifier is used to try to find the concept in the student's solution. It is in this step that all of the up-front hard work of creating a concept identifier starts to payoff in the following ways:

1) A reduction in manual assessment labor. A robot TA concept identifier is a labor saving device just like a washing machine, a car, and a cellphone are. With each of these devices, a large amount of up-front effort was needed to develop them. However, after this effort was invested, an enormous payback in reduced labor is enjoyed by their users on an ongoing basis.

   A concept identifier can search through a solution to try to find a concept in it in well under a second. Using robot TAs can reduce hours of assessing student work each week to a few minutes. The time that was spent doing repetitive manual grading can be spent working on higher-value tasks.

2) Increased assessment quality. In the robot TA teaching process, the quality of the assessment is built into a concept identifier using an iterative process. If the teacher becomes tired, sick, distracted, rushed, etc. during this process, they simply stop the process and start it again when conditions are more favorable. The end result of this process is almost always a high-quality concept identifier. This is similar to the way multiple takes of each scene are taken for a movie. Placing only the best of these takes into the movie increases its quality.

3) Increased visibility of the student's thought process. Before the robot TA analyzes a student's solution, it saves a copy of it. For a given problem, a typical student might submit the current version of their solution to the robot TA for assessment between 5 and 20 times. This data can be analyzed by other robot TAs to identify misconceptions a student may have.

4) Increased flexibility of the teaching process. The long feedback delay times that are inherent in the traditional teaching process limit the flexibility of the teaching process, and this is one reason why the traditional teaching process has not changed very much for over a century. When assessment times are reduced to under a second, deviations from the traditional assessment process become possible.

2.12 Step 2-12: Student Receives Feedback Within 10 Seconds

Instead of having the robot TA inform the teacher of the result of an assessment, and then having the teacher inform the student, the robot TA simply provides feedback to the student directly in under 10 seconds.

2.13 Step 2-13: Concept Found?

If the concept was found, the process will end in step 2-17. If the concept was not found, the next step is 2-14.

2.14 Step 2-14: Defects in the Materials?

1) Defects in the materials. Having the teacher test the materials in steps 2-5, 2-6, and 2-7 before giving them to the student reduces the probability that errors exist in them, but it does not guarantee they are error-free. If a student cannot get the robot TA's concept identifier to identify the concept in their work after repeated attempts, they will eventually ask the teacher for help. Any time a student asks the teacher for help on an assignment, this is an indication that one or more defects are present in the educational materials. Move to step 2-16.
2) No defects in the materials. Move to step 2-15.

2.15 Step 2-15: Student Changes Their Concept

If the concept identifier did not find the concept, and no major defects are present in the educational materials, then the student grasped the wrong concept. Nobody but the student is aware of this potentially embarrassing occurrence. It is true that the event was recorded and may eventually be looked at by the teacher, but the moment during which the student was informed they grasped the wrong concept was a private one.

During this private moment, the student can do one of two things:

1) Use reflection to form another concept that may pass the concept identifier. This is the ideal situation.
2) Randomly form another concept using little or no reflection. Most "poor" students will initially make heavy use of random concept formation, but over time they will slowly transition to using more reflection. A robot TA's < 10 second feedback response time makes this route to concept formation feasible.

   While this technique is less than ideal, randomly learning about wrong concepts is still learning, and it will eventually lead the student to discovering the correct concept. An analogy would be having students get to the top of a 10 foot wall in order to obtain a prize that is sitting on it. Some students will have the ability to climb straight up the wall, but many will not. However, those who can't climb straight up the wall will be able to get to the top of it if they use a ramp. Even if the ramp is a mile long, many students will walk it happily in order to obtain the prize. Learning by random concept formation is analogous to using a long ramp.

2.16 Step 2-16: Teacher Fixes Defects in the Materials and Makes Them Available to the Student

If the teacher determines that any of the defects that are listed in step 2-7 are present, then the teacher fixes the defects, and makes the updated materials available to all of the students who are working on the assignment.

If the teacher determines that none of the defects that are listed in step 2-7 are present, then one or more defects are present in the explanatory materials in step 2-8. This kind of defect is usually not severe enough to reteach the concept to the whole class, so the teacher usually clarifies the concept for the single student, and then fixes the defect in the explanatory materials for the next time they are used.

2.17 Step 2-17: Student Must Eventually Receive 100% On All Assignments

The conventional teaching process is so inefficient that it is not feasible to have a student keep redoing a given assignment until they receive 100% on it. This is unfortunate because any grade less than 100% means the student has wrong or missing concepts that will limit their potential for the rest of their lives.

The robot TA teaching process is so much more efficient than the conventional teaching process that it makes it feasible to require students to receive 100% on all assignments. One would think this would be an onerous requirement, but experience with using robot TAs in the classroom indicates this is not the case.

"Good" students often complete assignments with 100% without needing to use very many robot TA assessment/feedback cycles. For these students, the requirement of achieving 100% is not very much of a burden.

"Poor" students may need to use many robot TA assessment/feedback cycles, but in the end (and for many of them for the first time in their lives) they are actually grasping sophisticated concepts correctly. These students need to work harder than the "good" students, but they soon realize that the results they are getting is worth the effort.