Interactive Engagement - Hake, Mazur and more recent applications

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Introduction - What is Interactive Engagement (IE)?

I hear, and I forget
I see, and I remember
I do, and I understand.
- Confucius

"What is IE?" The opposite of this!

Do you remember when Steve asked us about our best and our worst learning experience at the beginning of the introductory lecture? Do you remember what your answer for the best learning experience was? It likely had something to do with the fact that a teacher somehow engaged you in the material, that you were challenged to interact with your coursemates. If that was the case, according to research on interactive engagement (IE), you should have also been likely to do better in that class. Let's go from here!

It has been widely acknowledged that the traditional teaching approach contributes problems with misconceptions and unsatisfactory conceptual understandings, as amongst other things oftentimes identified in the domain of introductory physics (Cahyadi, 2004). Unsatisfactory learning across domains can, among other things, be attributed to the fact that traditional teaching is typically composed of lectures requiring little or no active student involvement (hint: picture above).

As a result of observations of insufficient learning at the higher education level, there have been efforts to promote "active learning" in the classroom. Whilst the literature offers seemingly infinite definitions of interactive engagement, we will pull the working definition from a paper you have already read (skimmed - looked at - found on google scholar & potentially saved to your desktop), namely - Chi *et al.* (2009):

"The active/constructive/interactive observing hypothesis...refers to how actively engaged and constructive the observers are..In this article, these three terms will be used interchangeably and loosely. "

Since this definition sounds a little tautological to us, we are going to complement it with a more recent definition, taken from Georgiou & Sharma (2015):

“Active learning is the increasing of student participation, or ‘interactivity’, for the purpose of positively affecting student learning and attitudes”.

Since all good things go by three, and it helps to see a contrast with traditional methods of teaching, we’ll provide a third definition by *Hake* (2001) (about whom you’ll be reading in just a sec):

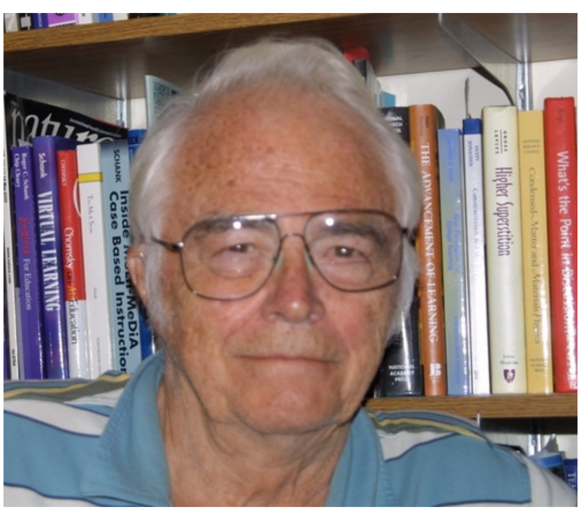
1. *Interactive Engagement* (IE) *methods* are those designed at least in part to promote conceptual understanding through interactive engagement of students in heads-on (always) and hands-on (usually) activities which yield immediate feedback through discussion with peers and/or instructors, all as judged by their literature descriptions;

2. IE *courses* as those reported by instructors to make substantial use of IE methods;

3. *Traditional* (T) *courses* as those reported by instructors to make little or no use of IE methods, relying primarily on passive-student lectures, recipe labs, and algorithmic-problem exams.

That shall suffice for now. Now on to Richard Hake, the father of interactive engagement.

Richard Hake (or: How to trigger the interactive engagement movement in Physics)



Why do researchers always pose in front of a bookshelf? Is it the halo effect? It certainly never fails to leave an impression (Hake - man of books).

Hake is something like the popstar of interactive engagement in education. The American was teaching Physics to prospective elementary teachers, but he became disillusioned when he found that the standard instruction of Physics was ineffective at the higher education level. Hake subsequently started experimenting with alternatives, such as breaking students into small teams and introducing peer-teaching strategies. He has been a keen defender of the argument that such techniques lead to better retention of knowledge, as well as a deeper, more elaborate understanding of the course material. An infamous meta-analysis he conducted in 1998 (including over 6,000 students) showed that interactive engagement techniques were associated with more than twice the average level of gain in learning than traditional methods. Hake is still active at Indiana University and he is also writing a blog with commentaries on educational reforms >> http://hakesedstuff.blogspot.co.uk

Introduction to Hake

As previously mentioned, interactive engagement involves learning through thoughtful and frequent interaction with the curriculum which is often achieved by questioning students or challenging them to think or do something that requires thought. It emphasises peer work and stimulates access to the curriculum by letting students work together on content-related activities. These instructional models whereby students partake in investigations and discovery have been shown to increase the learning of students in regard to their fundamental understanding in science. These methods allow students to formulate concepts on their own as opposed to be instructed in what to do. Even though investigations into the effectiveness of interactive engagement have normally involved sterile lab conditions they have been shown to improve the overall learning of students resulting in numerous interactive learning techniques. One original technique was developed and investigated in depth by the researcher Richard Hake.

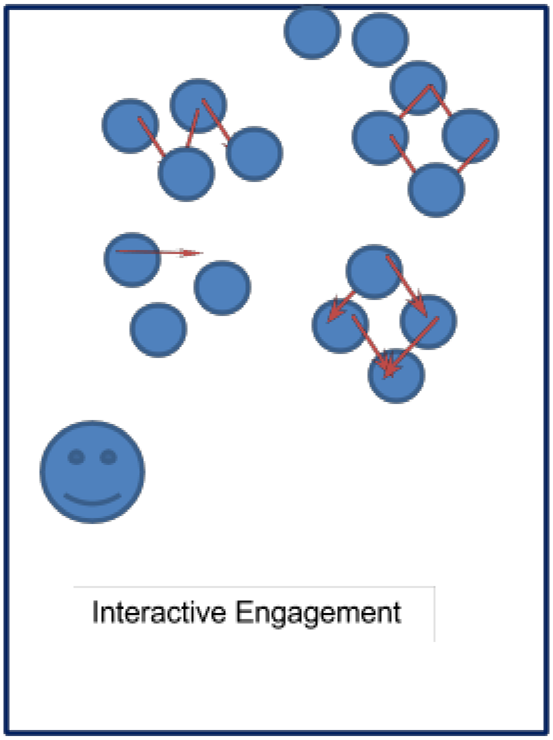
Personally I like to know a bit about a researcher before I look into their proposals so here is a brief description of Richard Hake. Hake was born in Colorado in 1927 and went on to complete a PhD in physics at the University of Illinois. He then became a professor in the departments of physics at Indiana University and from 1993 to 1996 he was on the editorial board for 'The Physics Teacher'. In addition to being an advisor for many university departments he is also involved in the Harvard online server for educational resources.

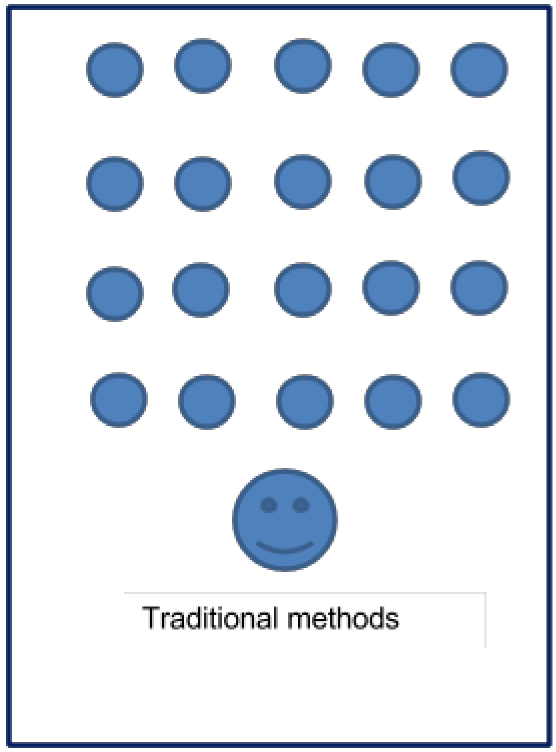
> 'Tell me and I forget. Teach me and I remember. Involve me and I learn'.
>
> → Chinese proverb as quoted by Benjamin Franklin

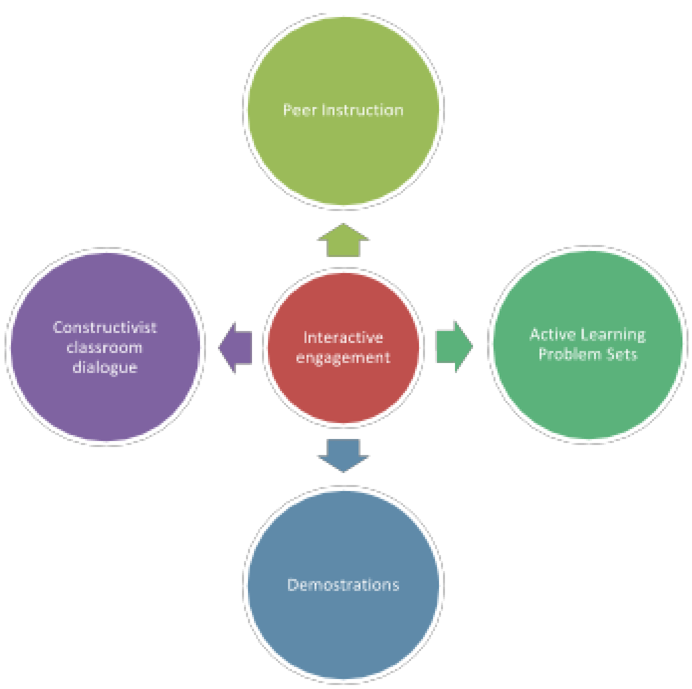
Theory

Whilst working as a condensed-matter-physics researcher, Hake found difficulty conveying physics to prospective elementary teachers. He became disillusioned with the theory based learning styles which were being implemented in schools which meant that students has little or no chance to pair their theoretical understanding with real world examples. After deeper investigation he found that standard instruction was not only ineffective in higher education but also in scientific research. In the 1980's Hake began to develop a program to improve introductory physics education which would allow student more interaction in their learning, naming the technique of interactive engagement.
Hake defines this interactive learning as methods designed to promote conceptual understanding through interactive engagement of students in hands-on and heads-on activities aimed to yield immediate feedback through group discussion with teachers and/or peers.

He suggests that students who have more involvement in their learning will better grasp the covered topics. Practically he felt that by breaking students into small teams, introducing a wider variety of problem-solving techniques and peer-teaching strategies may help students to become more effective problem solvers. As you can see, for Hake it is not only about making physics learning more effective for the sake of learning physics. His theory aims to not only increase the learning gains of students in regard to physics but to also increase students efficiency and capabilities as students as a whole, extrapolating their skills learned in interactive engagement onto other subject areas. Hake suggested that this form of learning programme increased the amount of information learned by students and also increased the quality of this stored information. In order to investigate this newly developed programme Hake conducted a comparative study in 1998 which investigated learning gains of 6000 students using both interactive engagement and traditional learning methods. This key paper in the field is described below.


Interactive Engagement


Traditional methods


Peer Instruction
Constructivist classroom dialogue
Interactive engagement
Active Learning Problem Sets
Demostrations

One big key paper

Interactive-engagement versus traditional methods: A six-thousand-student survey of mechanics test data for introductory physics courses

Richard R. Hake[a)]
Department of Physics, Indiana University, Bloomington, Indiana 47405

(Received 6 May 1996; accepted 4 May 1997)

A survey of pre/post-test data using the Halloun–Hestenes Mechanics Diagnostic test or more recent Force Concept Inventory is reported for 62 introductory physics courses enrolling a total number of students $N=6542$. A consistent analysis over diverse student populations in high schools, colleges, and universities is obtained if a rough measure of the average effectiveness of a course in promoting conceptual understanding is taken to be the average normalized gain $\langle g \rangle$. The latter is defined as the ratio of the actual average gain ($\%\langle \text{post} \rangle - \%\langle \text{pre} \rangle$) to the maximum possible average gain ($100 - \%\langle \text{pre} \rangle$). Fourteen "traditional" (T) courses ($N=2084$) which made little or no use of interactive-engagement (IE) methods achieved an average gain $\langle g \rangle_{T\text{-ave}} = 0.23 \pm 0.04$ (std dev). In sharp contrast, 48 courses ($N=4458$) which made substantial use of IE methods achieved an average gain $\langle g \rangle_{\text{IE-ave}} = 0.48 \pm 0.14$ (std dev), almost two standard deviations of $\langle g \rangle_{\text{IE-ave}}$ above that of the traditional courses. Results for 30 ($N=3259$) of the above 62 courses on the problem-solving Mechanics Baseline test of Hestenes–Wells imply that IE strategies enhance problem-solving ability. The conceptual and problem-solving test results strongly suggest that the classroom use of IE methods can increase mechanics-course effectiveness well beyond that obtained in traditional practice.

I. INTRODUCTION

There has been considerable recent effort to improve introductory physics courses, especially after 1985 when Halloun and Hestenes[1] published a careful study using massive

cent con[11] and pro[12] arguments as to whether a high FCI score indicates the attainment of a unified force concept. Nevertheless, even the detractors have conceded that "the FCI is one of the most reliable and useful physics tests currently available for introductory physics teachers" [11(a)] and

Hake's 1998 paper investigating the learning success of interactive engagement techniques versus traditional teaching methods is cited by 2887 papers. His research paper is based upon physics education but he suggests that the results found could have implications for a wider range of topics. Hake's reasoning behind his investigative study was the recent improvements that had; been made to introductory physics courses - mainly those using the interactive engagements practices we previously discussed. These recent improvements were not only driven by Hake but by others in his field who felt that the current practices in physics education were not allowing students to develop upon their factual knowledge. Halloun and

> Interactive engagement (IE) methods are those designed at least in part to promote conceptual understanding through interactive engagement of students in heads-on (always) and hands-on (usually) activities which yield immediate feedback through discussion with peers and/or instructors … traditional courses (T) are those … making little or no use of IE methods, relying primarily on passive-students lectures, recipe labs, and algorithmic-problem exams.

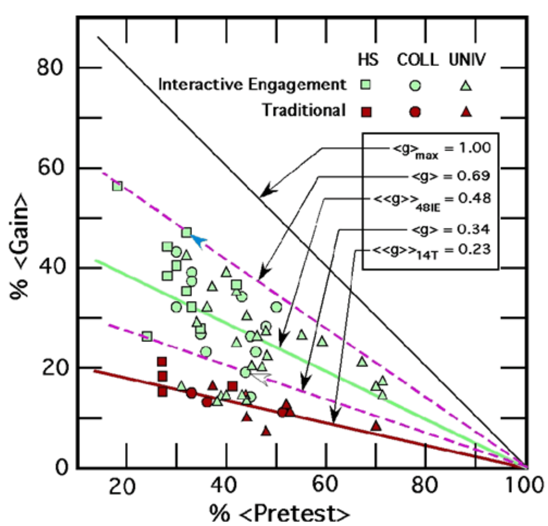
Hestens (1985) reported that the basic knowledge gained by students under convenient methods was largely independent of the professor and that traditional passive-student introduction to physics courses, even those taught by effective and praised teachers, left students with little understanding of Newtonian mechanics (a fundamental basis of physics education). Details of Hake's study have been split into sections below:

Sample - information was gathered from several papers, making a sample of 6000 students, which had investigated the effectiveness of either traditional physics education or interactive engagements physics techniques. In some cases, studies used had compared both of these education techniques.

Measures - Papers were chosen due to their use of the Halloun-Hestenes Mechanics Diagnostic Test, Force Concept Inventory and the Mechanics Baseline. These tests had been used by the sampled studies to investigate the recent effort to improve introductory physics education and were used due to their reliability in testing the conceptual understanding basic Newtonian mechanics. Individuals who scored low on these scales showed a lack of understanding of the basic concepts of mechanics.

Definitions - Within his study, Hake operationalized his key terms with interactive engagement meaning techniques which used hands-on methods to promote conceptual understanding with immediate feedback given through discussion with peers or with teachers. He defined traditional methods as those that used no interactive engagement techniques but implemented passive-student lectures and recipe labs.

Findings - Of the 14 traditional courses evaluated (N=2084) Hake found that the average gain in learning was <<g>>14+ = 0.23, 0.04. However average gains in learning for the 48 interactive learning courses (N= 4458) was <<g>>14+ = 0.48 + 0.14



I admit to having very little understanding of the result section of Hake's paper, but looking at his data it seems that interactive engagement techniques show more than twice the average level of gain in learning than traditional methods. Also, but due to the fact that his paper has been

cited so widely and that very few researchers have queried his results I'm just going to assume that they are valid.
Hake states that his findings show that interactive engagement methods enhance students problem-solving ability. In addition they increase the mechanics course effectiveness well beyond the gains obtained using traditional methods.

Suggestions for future research and implications -
Hake suggests that currently standards and measurements are desperately needed in physics education and are key features of the interactive engagement theory. In addition, Hake also includes a large list of more improvements which he suggests would improve the effectiveness of physics courses. These include the standardisation of test-administered practices, more widespread use of standardised testing, observation and analysis of classroom activities by independent evaluators and the reduction of possible teaching-to-the-test influence by drawing test questions from pools such that the specific questions are not known to the teacher.

Eric Mazur

A slightly less boring summary:
Most of the following information can be summarized by watching an interview with Eric Mazur himself:

https://www.youtube.com/watch?v=Z9orbxoRofI (for extra efficiency, try watching at 1.5x or even 2x speed!)

Mazur, a physics teacher at Harvard, experienced an epiphany about what entails effective learning when students in his class finally succeeded at figuring out a difficult concept simply by discussing amongst themselves. Subsequently, the notion of peer-assisted learning (think of PAL at Glasgow!) was born. Following his experience, Mazur developed the nowadays popular technique of peer instruction, which he described in detail in his book "Peer instruction - a user's manual" (Mazur, 1997). Mazur still *propagates interactivity in the classroom. Recent challenges to his theory involve claims that his arguments for peer instruction are simplistic, and that additional factors play a role whether or not a student will learn successfully.*

The Theory

Eric Mazur was a physics lecturer at Harvard in the 90s who received unusually high ratings from his students. While he thought this was due to his teaching skills, research at the time conducted by Halloune and Hestenes (1985) soon challenged his opinion – they found that students of a college level physics course lacked real-world understanding of the knowledge they had been taught. They had designed a test that assessed students' understanding of physics concepts in a more applied way by using real-world examples, such as the forces involved in a car crash. Considering his high ratings and his students' good performance on the course, Mazur set out to use the same test on his students, expecting a positive result. However he was promptly disappointed, with one student even asking him "Professor Mazur, how should I answer these questions? According to the way you taught me, or according to the way I usually think about these things?"

Mazur felt that he had failed – after all he wanted his students to truly understand the concepts of physics, not just be able to solve equations of numbers that were given to them. In his book he describes an epiphany he experienced during one of his lectures (Mazur, 1997). After spending ten minutes attempting to teach his students a concept and realizing that none of them had understood, he asked his students to discuss amongst themselves. Surprisingly it took no longer than a few minutes for everyone in the lecture hall to figure it out, and thus Peer-Assisted Learning was born: the teaching of knowledge and in-depth understanding amongst students themselves.

Eric Mazur consequently started to use this experience and knowledge in order to develop a teaching technique that claims to significantly increase the efficiency with which students may learn – making a career of it by writing a book called Peer Instruction – A User's Manual (Mazur, 1997).

Peer Assisted Learning – The Theory

Mazur believed (and still believes) that information transfer, i.e. the initial familiarization with knowledge, should not be the purpose of lectures. Instead he distributed information transfer to outside the classroom by assigning chapter readings and similar tasks as work *before* the class. His own lectures then had the task of knowledge assimilation, i.e. creating a depth of understanding and exploration of the knowledge. Using this framework he claimed to triple the efficiency of learning in his lectures.

He advocates several tools for this, such as electronic voting tools (-> clickers): a concept is briefly explained to the students, then they are given a question and asked to take an individual vote on what they believe is the correct answer. Once voting is complete, students then have to find someone who answered differently and try to convince the other person of their own answer. Mazur argues that the person with the correct answer is much more likely to convince the other, thereby creating a scenario in which most student pairings should conclude on the correct answer.

However when Crouch and Mazur (2001) set out to study this type of interactive learning, they found that not all students liked it: "The general complaint is that they have to do all the learning *themselves."* (Labert, 2012) While some may interpret this as laziness, no evidence was provided about this sub-group's academic performance changes relating to different teaching methods, thus the question of whether this preference for more traditional teaching had a positive or negative effect on their performance remains unanswered.

Nonetheless peer-assisted learning still remains popular and has called for a restructuring of the way knowledge is taught, specifically in higher education. The effects of this can be seen on a slightly smaller scale than originally intended by Mazur – for example provision of lecture slides and assigned reading before class, as well as integrating discussions amongst students about a posed question into the lecture. However Mazur argues that peer-assisted learning experiences difficulties partly due to an architectural problem – lecture halls as we know them do not lend themselves to sufficient peer instruction simply due to the fact that students must face towards the lecturer. He proposes a more interactive classroom that facilitates more social exchange of knowledge in order to further benefit from discussions to deepen understanding of the subjects (Labert, 2012).

One big book

Although old, Mazur's (1997) book provides a more detailed explanation and exploration of using peer instruction as a tool for transferring knowledge in a higher education setting. It explains how, why, and to what end different tools can be used in the context of physics, a focus which makes for one of the major criticisms of research in this field of study.

Peer Assisted Learning - Limitations and Criticisms

There have been issues with Mazur's work. For example Mazur (**not** Eric) and Doran (2010) argue that while peer instruction is a useful tool for higher education, teaching knowledge and helping students acquire an in-depth understanding of the topic at hand involves a much wider range of methods. Specifically, they argue that a variety of factors can affect a classroom – e.g. cultural background, learning difficulties, families, and communities. Thus Eric Mazur's view on transfer of knowledge appears simplistic at best, failing to consider a number of elements that can significantly affect the way students learn. Additionally, Mazur's work (and the use of classroom response systems) has received critique for relying too heavily on case studies and anecdotal evidence. Fies and Marshall (2006) explore this argument and emphasize the need for more scientifically rigorous research of these tools in order to ascertain whether they are truly effective and if so, how much.

As with Hake, Mazur's focus has exclusively been on physics, thus the possibility of applying peer instruction to other fields of study was not considered. So while the insight and tools he provides are extremely useful to lecturers in the field of physics, the extent to which they could be effectively applied to other fields remained a mystery at the time.

Yet, research has expanded since. One example is Scruggs, Mastropieri and Marshak's (2012) paper, which studied the use of peer-mediated learning in a population of middle-school aged children with disabilities. They found that using peer instruction led to a significant improvement of the students' performance in a variety of tests compared to those who had received traditional teaching.

Eric Mazur: Confessions of a converted lecturer

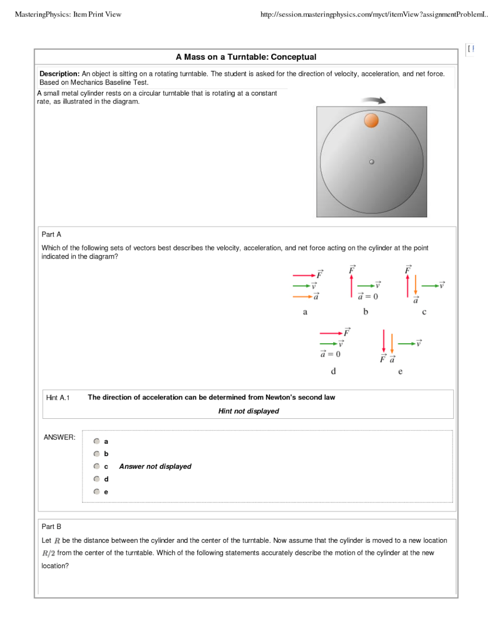
Do you have five more minutes to spare? This is Eric Mazur talking about how he developed the method of peer instruction, after observing the poor progress students made in his introductory Physics classes at Harvard.
https://www.youtube.com/watch?v=hbBz9J-xVx

Measures of IE effectiveness

In order to get quantifiable data on the effectiveness of interactive engagement teaching methods, researchers needed to implement tests to get an idea of student gains in understanding of basic newtonian principles. Several tests had been developed in the past which measured student's knowledge of basic topics and principles which were deemed valid and reliable measures of ability. Researchers looking into the effectiveness of interactive engagement techniques have implemented at least one of these tests pre teaching and post teaching in order to identify gains brought about through updated teaching styles. Examples of the tests used are detailed below.

The Mechanics Baseline

This widely used test was developed by David Hestenes and Malcolm Wells and is frequently used as a measure of ability in physics classes. The instrument comprises of 26 questions that were based upon interviews with students about their misconceptions on basic topics in Newtonian mechanics. The test covers concepts in kinematics (linear and curvilinear motion), basic principles (Newtons' First, Second, and Third Laws, superposition principle, energy conservation,impulse-momentum, and work) and special forces (gravity and friction). In addition the test is designed to probe concepts and principles that cannot be grasped without formal knowledge about mechanics, and require a quantitative approach to answer them that is more involved than plugging in numbers to formulas. A sample question from the test is shown below.


MasteringPhysics: Item Print View http://session.masteringphysics.com/myct/itemView?assignmentProblemI...

A Mass on a Turntable: Conceptual

Description: An object is sitting on a rotating turntable. The student is asked for the direction of velocity, acceleration, and net force. Based on Mechanics Baseline Test.

A small metal cylinder rests on a circular turntable that is rotating at a constant rate, as illustrated in the diagram.

Part A

Which of the following sets of vectors best describes the velocity, acceleration, and net force acting on the cylinder at the point indicated in the diagram?

Hint A.1 **The direction of acceleration can be determined from Newton's second law**

Hint not displayed

ANSWER:
- **a**
- **b**
- **c** ***Answer not displayed***
- **d**
- **e**

Part B

Let R be the distance between the cylinder and the center of the turntable. Now assume that the cylinder is moved to a new location $R/2$ from the center of the turntable. Which of the following statements accurately describe the motion of the cylinder at the new location?

1 of 2 10/17/2010 3:18 PM

Additional information can be found in:

D. Hestenes, M. Wells

A Mechanics Baseline Test

The Physics Teacher, 30, 159-166, (1992).

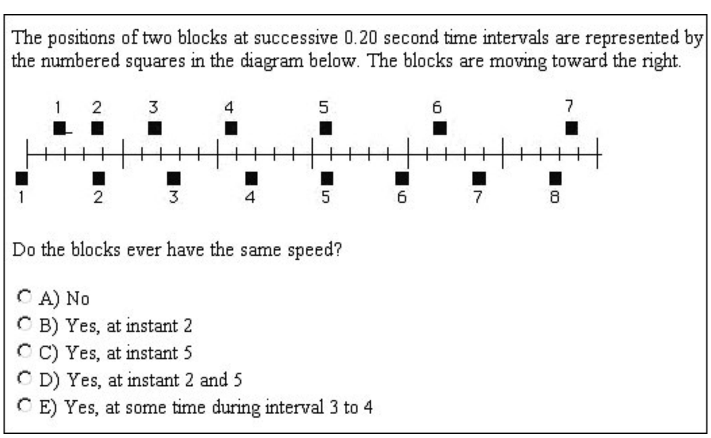
The Halloun-Hestenes Mechanics Diagnostics Test

In 1985, Halloun and Hestenes introduced a "multiple-choice mechanics diagnostic test" to examine students' concepts about motion. It evaluates student understanding of basic concepts in classical (macroscopic) mechanics. This test was later developed into the force concept inventory. Its key principles along with methods were incorporated into the new inventory used to detect students knowledge of the Newtonian concepts of force.

The Force Concept Inventory

With the emphasis of methods of IE in the field of physics, it is noteworthy to point out *how* gains in conceptual understanding through the implementation of IE methods are inferred. The most commonly used measure is the “Force Concept Inventory” (FCI), a qualitative test with 30 multiple-choice questions to detect student knowledge of the Newtonian concepts of force. The test was developed by Hestenes, Halloun, Wells, and Swackhamer in 1985, and is nowadays seen as the gold standard for a conceptual inventory in the physical sciences. The test itself essentially requires a forced choice between Newtonian concepts and common sense alternatives. It is used up to this day to test student knowledge and thereby, it helps to compare the efficacy of individual Physics courses (e.g. Ding & Caballero, 2014).

The FCI was originally developed to improve on the *Mechanics Diagnostic Test* (Halloun & Hestenes, 1985), but its wider impact has gone far beyond physics, with implications for what constitutes good teaching and how applicable learning can be triggered.



<<Here is an example question taken from the FCI.

What is the wider importance of the FCI? The test took a lot of time to develop, and it was the first qualitative inventory to test students' domain-specific knowledge in a qualitative fashion. Most importantly, it revealed the notable gap between students' passive understanding of introductory physics and their ability to apply the basic concepts of physics. For example, Hestenes (1998) found that whilst at the beginning of the course, nearly 80% of students could state Newton's Third Law, the FCI revealed that less than 15% had a deep understanding of it.

The test thus showed that a lot of higher education learning in physics was *shallow*. To put it into Hestenes, Wells & Swackhammer's (1992) terms: *"(Students) have been forced to cope with the subject by rote memorization of isolated fragments and by carrying out meaningless tasks. No wonder so many are repelled!"*

The FCI therefore triggered efforts to introduce opportunities for active engagement in the classroom - which subsequently spread from Physics to other domains. So if it hadn't been for the FCI, chances are that the 'interactive engagement movement' had never entered the classrooms.

Food for thought Would it be recommended to introduce equivalent tests for introductory Psychology? Like the Freudian Defence Mechanisms Inventory (FDMI)? Or the Big 5 Inventory (B-5 I)? How do *you* make sure you obtain a *deep* and *applicable* understanding of your course material?

Recent applications of IE

Foreshadowing summary

In line with the popularity of IE, this will be something of a lengthy section (brace yourself!). You can already glimpse a beautiful table below - this will be a summary of the ***different IE methods****. Because* ***peer instruction*** *(PI) and* ***personal response systems*** *are especially popular methods, we will go into some detail about them. In this context, you'll have the pleasure to engage in the supposedly n° 1 paper in the field (Steve said so, it must be true) - Smith et al.'s (2009) study on why peer discussion works. In the following, we'll introduce a bunch of* ***research groups*** *which are currently trying to make the world of learning and teaching a better place. From there you'll be temporarily redirected to some youtube fun. After a very short and very subjective thought on the difference between* ***U.S. and U.K. teaching*** *on the HE level, we'll present you with an overview of the* ***different academic disciplines*** *in which IE has been employed, including links to some of the more relevant studies. Afterwards, it'll be time for some* ***critical thinking*** *- we'll discuss the extent to which interventions are comparable, and we'll also try to endow you with a feeling for what would be a* ***high-quality paper*** *on IE. After a summary of the potential benefits of IE, we'll apply our reading by suggesting a bunch of* ***reforms*** *on the HE level. After a bunch of* ***suggestions for future research****, we will draw our personal conclusions.*

Different methods of IE: close-up

IE Method	What is it?
Peer instruction (Mazur, 1997)	After individual consideration of short conceptual MCQs, students try to convince their neighbours that their answer is the right one. The instructor subsequently presents the right answer.
Personal response systems (Anthis, 2011)	"Clickers" are typically coupled with peer instruction for students to vote their answers via such electronic systems. An electronic overview of the percentages of answers chosen helps the teacher to specifically tackle students' misconceptions.
Active Learning Problem Set (ALPS) *(specific to Physics)* *(van Heuvelen, 1991)*	A set of worksheets which provides step-by-step guidance for students systematically to solve physics problems. Includes pictorial, physical and mathematical representations of a problem.
Constructivist Classroom Dialogue (Mestre, 1991)	The instructor facilitates by asking qualitative questions to assess students conceptions, and subsequently points out their discrepancies with actual concepts
Demonstration (Sokoloff & Thornton, 1997)	(1)Instructor describes demonstration (2)Students make individual predictions (3)Students engage in small-group discussions (4)Students note final group predictions (5)Instructor carries out demonstration. (6)Discussion of results. Demonstrations can be incorporated in any teaching approach.

Peer instruction

Have you ever felt like you have been lost underway in lecture? The benefits of peer instruction appeal to those of us that wish they could sometimes pause the lecture and let their brains catch up. This is because this method leads to a "chunking" of the lecture: a lecturer will break up his/her lecture to ask MCQs to the students, thereby testing their understanding of the concepts presented (Smith *et al.,* 2009). Typically, a student first answers the question individually, and then a histogram of the class' responses may be displayed to the class. In the case of disagreement, students may discuss their thoughts with their neighbours, and revote, before the correct answer is displayed. In summary:

(1) individual response by students (often by using a clicker, see below)
(2) Discussion with neighbour (mostly pre-assigned groups)
(3) Opportunity to revote on the same question
(3) Classwide discussion follows, led by student explanations and the instructor modeling their way of understanding the problem.

As Simon and Cutts (2012) point out, each of these steps is necessary for distinct reasons: The initial solo vote ensures that every student is to some degree engaged with the problem. The group discussion stage leads students to articulate their understanding of the concepts, and come to a group consensus. The second vote (step 3) prepares the facilitation role of the instructor: his/her follow-up explanations and feedback are especially valuable, as students will now be primed to connect explanations with their personal understanding.

Efficacy of Peer Instruction (bonus: n° paper in the field)

As previously mentioned, the method of peer instruction was developed by Mazur. Notably so, this method has evolved past Mazur, and past physics, and is now employed across disciplines. Impressively enough, this method tends to improve learning twofold over the standard lecture format (Crouch & Mazur, 2001; Hake, 1998). But *why* does this method work? Or, more specifically: Is this method effective because (1) active engagement during discussion with other peers leads to higher conceptual understanding, or because (2) students simply choose the answer provided by the seemingly most knowledgeable peers? Using paired sets of similar questions ("isomorphic questions"), Smith *et al.* (2009) found that it was the student *discussion,* and not merely copying an answer from the most knowledgeable student in the discussion group, which evoked improved performance. So even within naive groups, in which nobody knew the answer, the sole act of discussing made it more likely for students to induce the right answer! Think about the implications of this! This article really highlights the invaluable role of peer discussion in learning - so get those discussion groups together before the finals!

Why Peer Discussion Improves Student Performance on In-Class Concept Questions

M. K. Smith,[1]* W. B. Wood,[1] W. K. Adams,[2] C. Wieman,[2,3] J. K. Knight,[1] N. Guild,[1] T. T. Su[1]

When students answer an in-class conceptual question individually using clickers, discuss it with their neighbors, and then revote on the same question, the percentage of correct answers typically increases. This outcome could result from gains in understanding during discussion, or simply from peer influence of knowledgeable students on their neighbors. To distinguish between these alternatives in an undergraduate genetics course, we followed the above exercise with a second, similar (isomorphic) question on the same concept that students answered individually. Our results indicate that peer discussion enhances understanding, even when none of the students in a discussion group originally knows the correct answer.

Because peer instruction is oftentimes coupled with the use of clicker, I'll also tell you a bit about these "personal response systems", and whether they are really necessary to prompt thinking in students.

Personal Response Systems

Clickers, often referred to as "personal response systems", are especially popular at American and Canadian as a means to increase students' understanding of the subject matter. They also tend to reflect the local capitalist approach to higher education: one clicker fares at around $40.

Especially in the United States and Canada, the employment of "personal response systems", also referred to as "clickers", aims to generate instantaneous feedback from students. This method tends to be coupled with the just mentioned peer instruction (PI) (Mazur, 1997).

Are personal response systems an effective strategy to increase learning? The literature indicates that both correct answers, and students' confidence in their answers, tend to increase after peer discussion (Crouch & Mazur, 2001; Knight & Wood, 2005; Mazur, 1997). However, one very informative paper ("is it the clicker, or is it the question?") by Anthis (2011) found that the successes of clicker use had been falsely attributed. In fact, it was uncovered that it was the *question* which led to higher mental engagement of students, not the clicker in itself. Interestingly, classes in which response to questions was prompted by raising one's hand showed better scores than those using clickers! To me, this study shows that ways of implementing IE methods needn't always be expensive - sometimes, the old-school method of thinking hard, and stretching one's limbs in the vertical position can also do the trick.

Currently active research groups

Because it is insightful to see what current educational research is up to, we are going to introduce 2-3 currently active research groups (from around the globe).

(*A very unrelated research group from the 1970's in Australia. Hare Krishna maha-mantra?)*

The Mazur Group at Harvard

When you were reading about Mazur, you might have wondered whether he is still alive and well. In fact, Mazur currently leads his own research group at Harvard, dedicated to "improving education through research" (http://mazur.harvard.edu). As mentioned, it was at this location where peer instruction was originally developed in 1991. Nowadays, the group further tests the efficacy of this method, but also looks at the utility of classroom demonstrations, as well as the gender gap in physics.

One current research project that struck our interest is a project on understanding the benefits of *confusion*: "We find that student expressions of confusion are negatively related to initial performance, confidence in reasoning and self-efficacy, but positively related to final performance when all factors are considered simultaneously." So next time your mind hits the wall, just remember that learning is a process, and with enough perseverance, you will get there eventually!

The Physics Education research group at the University of Colorado at Boulder

The University of Colorado at Boulder is another forerunner in implementing IE at the higher education level. The most notable goals of the local physics education research group (>> http://www.colorado.edu/physics/EducationIssues/) include "examination of successful educational reforms and replication studies of such reforms, and student problem solving in physics."

One of the currently most active researchers into the how's of learning and teaching is a man named Steven Pollock. Watch him talk about the art of teaching Physics for 2.30 min in a somewhat promotional, yet insightful video (bonus: emotive music playing in the background):
https://www.youtube.com/watch?v=ioYYUY2pSEI

Pollock was chosen to be one of the 2013 U.S. professors of the year. This man certainly doesn't like to take chances in the classroom - Follow up on an interview with him here >>

http://www.colorado.edu/news/releases/2013/11/14/cu-boulder-physicist-steven-pollock-named-2013-us-professor-year

Pollock's colleague, Noah Finkelstein, said some interesting things about the nature of learning:

"Learning is an incredibly complex issue, but there are some general principles involved. Actively engaging students is essential. Learners must be active intellectually, physically, psychologically and cognitively. Education is not simply a matter of information delivery; it's a form of socialization, of bringing students into our culture. That's the grand challenge. We can demonstrate with consistency and reliability that when students are engaged and challenged, when they interact with each other, they learn."

Read the whole interview here >>
http://connections.cu.edu/news/five-questions-for-noah-finkelstein/

These are obviously just a snapshot (and a good opportunity to distract you with youtube videos!), and it has almost become mainstream to direct efforts not just into the what, but the how of teaching. Other examples include:

> Education research group at LSE, whose director Anne West has been put in charge of leading educational reforms to reform the French school system
> *Subject Pedagogy Research Group at Oxford*, with cross-disciplinary efforts
> "Herg" - the "Higher Education Research Group" at Edinburgh
> Quintin Cutts at your local Glasgow! He helps to implement computing science at schools in the UK and abroad, thereby translating his research findings in applied settings.

Just a thought - IE across the globe?

Maybe efforts for interactive teaching are still bigger in the States. The author of this text studied at the University of California for a year - and was forced to make friends in lecture through the regular prompts to engage in peer instruction. Lectures tended to feel like a dialogue with the teacher, and there was a real black market for the the pricey iclickers. Maybe the Anglo-Saxon world of academia is still a little in love with its confrontational teaching. Not that peer discussion in the U.S. was always super-helpful - because exam results were curved, everybody was statistically competing against everybody. Rumors protruded that "groupwork" sometimes led to the conscious deception of groupmates in the competitive business department. So in the end, overall competitiveness almost killed the fruits of interactive engagement.

IE across disciplines: engagement beyond Physics

If you are anything like us, you will have by now thought: "Is IE just from Physics, in Physics and for Physics?!?" And whilst physics remains the birthplace of applied efforts in teaching, other disciplines have followed the call of implementing IE strategies in the classrooms. Exemplary papers from across disciplines of can be found in below's table.

	Summary
Physics	
Georgiou & Sharma (2015)	In two out of four Physics thermodynamics modules at the University of Sydney, eight-step interactive learning demonstrations were introduced. Results showed an intermediate effect size, and qualitative interviews demonstrated high student satisfaction by being more engaged in lecture.

Deslauriers, Schelew & Wieman (2011)	Deliberate practice intervention at a Physics course at UBC in Canada showed that use of formative assessment and direct feedback nearly doubled students' midterm scores, compared with the control group. Additionally, student feedback about the intervention revealed extremely high satisfaction scores.
Chemistry	
Gold, McCreary, & Koeske (2006)	In this study, advanced undergraduate students were assigned the role of peer instructors for a chemistry lab. Results showed that students in the peer instruction groups performed significantly better than those in the traditional teaching groups.
Computing Science	
Simon & Cutts (2012)	Peer instruction is especially important in computing science, because high failure rates and lack of students interested in CS require insight into what students find difficult about learning computing.
Porter *et al.* (2011)	A replication of Smith *et al.* (2009), confirming that students heavily benefit from peer discussion in computing science.
Biology	
Knight & Wood (2005)	Switching from standard to IE teaching within two semesters showed that students displayed better conceptual understanding of developmental Biology following the intervention.
Armbruster, Patel, Johnson & Weiss (2009)	Implementing active and problem-based learning amongst other things led to both increased positive student satisfaction (survey), as well as significantly increased academic performance.
Genetics	
Smith *et al.* (2009)* *** best paper in the field!**	Testing why the use of personal response systems ("clickers") in lecture is effective, it was found that it was the discussion component- and not "imitating" the right answer from a knowledgeable student - which explains the efficacy of such personal response systems. *In short:* even totally naive groups could discuss their way to the right answer!
Psychology	
Yoder & Hochevar (2005)	In one class of the 'psychology of women' (what a class!) in which students were presented with active learning techniques, compared to lecture, autonomous readings, or video without discussion coverage, students ended up scoring significantly higher in exams.

Morling, McAuliffe, Cohen & DiLorenzo (2008)	Two out of four tutorial groups were engaged with clickers in class. Despite minimal use, these two groups reported slightly higher exam scores, which students attributed to their increased motivation to attend class.
Sociology	
Mollborn & Hoekstra (2010)	This article discusses the utility of personal response systems (“clickers”) in sociology, whilst also evidencing that clickers in sociology may positively affect participation, critical thinking and classroom interaction dynamics.
History	
Scruggs, Mastropieri, & Marshak (2012)	This study not only tested the effects of peer instruction in the subject of US History, but also used a sample of children with disability. Varying from most studies in the sciences of higher education and from normal learning condition this way, they found that peer instruction significantly increased academic performance.

Some food for critical thinking

Now we will give you some pointers for critical thinking on this topic (sorry if you still haven’t digested the trauma of the CR-writing)! Firstly, we note that the IE research has very variable effect sizes, a product of the sheer number of variables that can inhibit or facilitate student learning - Turpen & Finkelstein (2009) phrased this in an accessible way: classrooms are “unique cultural systems”. The inconsistency in terminology presents a further obstacle to making solid cumulative judgments about efficacy. To round things off, we’ll teach you how to spot good and bad papers on IE. Heads on!

To what extent are interventions comparable?

As we learned in lectures, the field of educational research (and really, any applied research) wants to identify the **effect size*** of a certain intervention. Why is it difficult to make reliable comparisons of the effectiveness of educational interventions? Because of the number of variables in the equation! Besides the teaching style and IE employed, student learning is modulated by additional factors as: student interest, knowledge base, previous experience, assessment, teachers, courses, departments and institutions (Ramsden, 1992). Cahyadi formulated the contingency of interventions on a particular environment as follows:

"Undertaking research in a certain educational environment may lead to a more accurate indication of how to improve the quality of learners in that particular environment."

***hint:** effect size is the magnitude of the difference between groups, typically calculated as Cohen's *d*.

Is interactive engagement all the same? Of course not. A study by Turpen & Finkelstein (2009) has shown that the implementation of peer instructions differs among faculty staff - e.g. despite Mazur's step-by-step plan for peer instruction, some staff allow significantly more follow-up student discussion than others. Focusing on the individual implementation of PI by six different members of staff (which were all referred to using colors - "Prof. Green" vs. "Prof. Red"), the researchers found that individual variation in implementation was associated with disparate opportunities for students to ask questions, interact with the instructor and communicate scientific ideas publicly.

They conclude from this that classrooms are “unique cultural systems” (or “microcultures”), with norms of behavior arising out of the repeated use of shared practices. In other words: The social nature of teaching and learning, with theoretically infinite variables interacting, inevitably produces variation in efficacy across settings.

This perspective certainly helps to understand the variation of effect sizes found in past interventions (Hestenes, Wells & Swackhamer, 1992; McDermott & Shaffer, 2002; Pollock & Finkelstein, 2008).

Besides the domain-specificity of the effectiveness of certain interventions, cross-study comparisons are hindered by an additional, more controllable issue:

More specifically, current research on interactive teaching interventions often operates under differing terminology, making comparisons and cumulative assessments somewhat difficult. For example, Deslauriers, Schelew & Wieman (2011) talk about deliberate practice, whilst Georgiou & Sharma, 2015 (and many others) talk about “(inter)active learning”.

The varying quality of IE papers

As with most research, the quality of papers assessing the efficacy of IE interventions displays large variability. To help you to develop a more fine-tuned intuition for what you should look out for, an ideal studyshould display most or all of the following criteria:

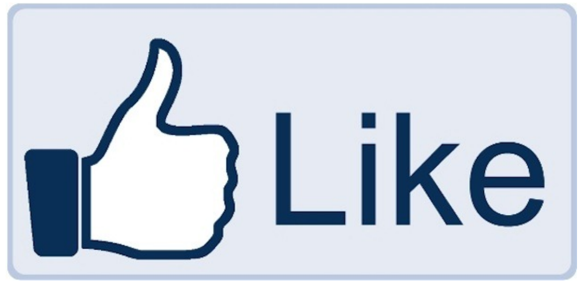
→ **manipulation:** keep students blind to IE intervention (if possible)
→ **comparison:** have a control group (you'd be surprised to see how many studies do not have a control group)
→ **implementation:** control for extraneous variables
→ **measurement:** ideally collect both quantitative (e.g., through the FCI) and qualitative markers of student progress in understanding

Example of a POOR study

Cavanagh (2011): *In Australia, an education class was exposed to "lectorials" – a blend of lectures and tutorials, i.e. every 10-15min, lectures switched with cooperative activities (e.g. case studies, group discussions). Qualitative feedback by the students via a questionnaire showed that students appreciated opportunities for deeper learning, and critical thinking.*

:-(Whilst this study might have shown that students enjoy cooperative activities in class, only qualitative data was gathered, there was no control group and no additional controls. So all we can take from this study is that students seem to enjoy lectorials!

Example of a GOOD study



Turpen & Finkelstein (2009): *By the example of peer instruction, the researchers show that teachers differ in ways in which they implement peer instruction, leading to differences in classroom discussion, and classroom cultures.*

What makes this study good is that it took quantitative *and* qualitative measures of teacher's variation in implementing peer instruction. The study is therefore informative in the regard that it helps to explain the big variance in effect sizes of peer instruction. Another informative aspect would have been to see how this variability translates into students performance.

Example of a VERY GOOD study

Deslauriers, Schelew & Wieman (2011): *Deliberate practice* intervention at a Physics course at the University of British Columbia in Canada showed that the use of formative assessment and direct feedback nearly doubled students' midterm scores, compared with the control group. Additionally, student feedback about the intervention revealed extremely high satisfaction scores.*

:-) This study has all that it takes! Notable are the careful implementation of the experimental condition, as well as the gathering of both quantitative *and* qualitative feedback! Also nice to see how these two converged - students enjoyed their classes more, attendance increased, and this finally translated into higher exam scores.

* *deliberate practice* in this case means that students were asked a series of challenging questions and tasks; had to make predictions; engage in problem-solving activities; received frequent feedback; as well as constant feedback from fellow students and the instructor.

Mini Conclusion on this matter:

Of course, not every study can “have it all”, and a study like Cavanagh (2011) might come to be a good starter (in this case, it was surprising that students expressed a perceived usefulness of lectorials, as previous feedback had shown such an intervention to be potentially useless). However, if in the near future (i.e., once you start revising) you should be wondering whether it’s worth making big inferences from a study - you may tend to our mini-checklist above. Check!

Final Points

Time to wrap things up. After a summary of the potential benefits of IE, we’ll apply the material covered by suggesting how teaching on the higher education level could be improved (lectures could be so fun!). Suggestions for future research include the further extension of IE to non-physics domains, and IE in high schools should help to prevent later resistance to funny IE interventions. And then you’ve already made it, and you may indulge in beautiful, thoughtful conclusion. Congratulations and thanks for taking an interest into IE learning and teaching!

Summary of the potential benefits of active student engagement in lectures

Higher motivation: Active learning is linked with higher student motivation (Machemer and Crawford, 2007)

Better retention: students who contribute and feel engaged in lectures retain new knowledge for longer, compared with when they simply hear or see it (Lujan & DiCarlo, 2006).

Promoting deep learning: triggering responses from students (e.g. by questioning or group problem-solving activities) promotes deep learning, where they don't just memorize facts, but relate new ideas to current knowledge (Biggs, 1999).

Higher confidence: students feel more confident about the class materials (Cherney, 2008).

Independent and critical thinking: Giving students opportunities to think critically helps to shape them into self-directed learners capable of weighing evidence from a variety of sources, synthesize information and subsequently communicate ideas (Justice et al., 2007).

Self-directed learners: interactive interventions help students to take greater responsibility for their learning (Niemi, 2002).

Suggestions for implementations in Higher Education - and why!

What Introduce peer discussion in lectures (with or without clickers!)

Why Because even if nobody knows the answer, the sole act of discussion is more likely to generate a better understanding for difficult concepts (Smith *et al.,* 2009).

What Instructors should explain the rationale and purpose of the IE activities, before they are implemented. This relates especially to classes with students from more traditional teaching backgrounds.

Why Students from more traditional teaching background may be apprehensive about being expected to engage in lectures and tutorials (Cahyadi, 2004).

What IE activities should be reflected in exams, e.g. by having students recall demonstrations conducted in the classroom.

Why It will encourage students to participate in the learning process seriously (Cahyadi, 2004).

Suggestions for future research - or: what is still uncertain in the IE literature

As inherent in in the recency of most of the IE applications (clickers!), there remains a vast scope for what is still to be explored. For example, there is still uncertainty as to how successful attempts at triggering active learning really are (Prince, 2004), with large variability in effect sizes across IE implementations. Additionally, with the difference across IE applications, there is a lack of consensus about what the interactive learning process entails (Freeman *et al.,* 2014). Therefore, a streamlining of terminology (deliberate practice? active learning?) would be helpful to make comparisons across studies feasible. Most importantly, IE has still been mostly applied in a narrow number of settings, notably in physics, engineering and education classes. Whilst our table of "IE past physics" (you should look at it! it even has live links!) shows examples of IE implementations past the hard sciences, such efforts are comparably sporadic, and a lack of subject-specific inventories to assess the success of respective interventions further limits inferences about their quantifiable efficacy. Drawing from the examples given of good and bad studies, future research should preferably include experimental controls, such that progress made can be compared to a baseline value. We also addressed the tendency in studies to collate *either* quantitative (via pre-/post MCQ content assessments) *or* qualitative data (either instructor or participants feedback on intervention through surveys or interviews). If possible, future studies should simultaneously collect qualitative *and* quantitative data on the efficacy of IE interventions (as e.g. done by Turpen & Finkelstein, 2009). This would help to facilitate judgments of whether objective and subjective markers of effective interventions converge.

Conclusion

It is important to note that despite such ample evidence for the effectiveness of IE interventions, lectures still represent the dominant form of university instruction (Lammers & Murphy, 2006). This is despite the fact that research does seem to suggest that Hake's interactive engagement technique improves the educational attainment of individuals, though this remains specific to introductory physics courses. Studies have found that students who undergo variable methods falling under the IE umbrella term have higher conceptual understanding and increased problem-solving than students who remain exposed to traditional teaching methods. As the application of IE is biased on the level of education (implement and test them at high schools too!) and subject domains (which IE method would be best in Psychology?), the broader applicability of different IE methods will constitute a major future challenge. Part of this will need to be a consideration of the different challenges and typical misconceptions inherent within a subject area. Of course, restructuring teaching systems towards IE is costly, as it requires thorough teacher and lecturer training - unfortunately, such fiscal variables will eventually determine the way in which IE will be studied, and implemented. As Mazur himself was aware, things are further complicated by moderating individual difference variables, such as learning disabilities and students' personal preferences (Scruggs, Mastropieri, & Marshak, 2012). To facilitate a careful implementation of IE methods, it would be beneficial to gain more feedback from student about their beliefs of the effectiveness of IE, as well as teachers' perspectives of the tradeoff between the costs and benefits of IE. IE is a great area for critical thinking, because despite ample investigations and replications, hard, consistent evidence for the efficacy of different IE interventions *across* domains is yet to be provided. Whilst the 'classrooms as microcultures' view highlights that variability of effect sizes is inherent in the nature of the matter at hand, if implemented carefully, IE promises a more social, rewarding and empowering learning experience.

Thanks for reading about IE!   A project® by Harriet, Paul & Viktoria.

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