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Structure of the Book

This book is intended for several overlapping audiences: students and teachers in science courses in high schools; students and teachers in science courses in college; and a much larger group of people who already have a college education, which convinced them that they wanted nothing to do with math, sciences, and especially physics. At the same time, the book is addressed to the educators and reformers who are deeply interested in creating opportunities for productive learning by generations of students. About a century has passed since Einstein's work was done, and it is not an exaggeration to say that 99.9% of the American population has not the faintest idea of the meaning and consequences of his contribution, and we include here many scientists who are not physicists. But our goal is not to popularize science. We aim to explain what is missing in the educational system and what reformers need to think through in order to become able to begin a process of meaningful change. Our goal is not to provide a ready-to-follow instruction how to do it, an instruction that everybody will be able to follow without effort, but to point out what needs to be achieved for those who are interested in the heart of educational matters. We make our point by first describing many examples of what is involved, including what happens in classrooms and what $E = mc^2$ means. Having analyzed these examples, we will come to basic conclusions concerning reform toward the end of the book. The reader is asked to remember, as we indicated above, that this book is in no way meant as a popularization of Einstein's work, *but rather as an attempt to help readers acquire far more than a superficial grasp of how Einstein accomplished what he did and what this implies for the future of educational reform.*

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In deciding to write this book, we knew we had to confront several problems. The first problem is that teaching subject matter requires that you make as explicit as you can what you mean by learning. As we make clear in this book, we have concluded that one basic reason for the failure of educational reform movements is a superficial and fuzzy conception of learning. More specifically, the criteria for distinguishing between contexts of productive and unproductive learning do not exist in any readily available form and go undiscussed.

The second problem is that the teaching of science in our high schools and in introductory science courses in college is scandalously poor. If that statement represents a consensus, it has the effect of glossing over the fact that the quality of teaching non-science subject matters does not come up smelling like roses.

The third problem is that we have developed a conception of a context of productive learning in which the teacher-student interpersonal relationship is center stage. But in writing a book, we and the readers are not in an interpersonal relationship. The readers cannot ask us a question, nor can we ask them or see their body language. In a context of productive learning the interpersonal relationship is, among other things, one of mutual safety and trust.

There was, however, one feature of our audience that we felt was unquestionably valid: They would approach the book with feelings of insecurity, even anxiety. And yet they were curious about what they had heard or experienced about science, math, or Einstein. This was not our imagination; such feelings are precisely what students told us they had. For us, their curiosity had to be nurtured, encouraged, and developed. That meant to us that our starting point had to be that curiosity.

In our experience, this curiosity—curiosity about any subject matter—about what made the subject matter both interesting and important was no small issue. In our case, we decided that the starting point was, How come issues surrounding the measurement of the speed of light ultimately led to $E = mc^2$? In other words, the worst starting point would be to plunge into the details of the formula $E = mc^2$ itself. It was exactly this kind of decision making that explains why we devote two chapters to four Hollywood films that show the viewer the differences between contexts of productive and unproductive learning in the lives of young people and their teachers.

This sensitivity to where students are psychologically coming from is reflected in the fact that in this book there are very few equations, and the ones that are included in the main text only involve addition, subtraction, multiplication, and division. One of the goals of this book is to help readers grasp the basic problems Einstein was confronting, how he solved them, and the consequences of his solution. And perhaps the most difficult problem for people to understand is that Einstein pulled the rug, so to speak, from under the millennia-old idea that time was absolute, which means that it is the same for all observers regardless of where they are and

how fast or slow they move with respect to each other. As we emphasize in these pages, the millennia-old conception of time works well for us earthlings in our daily existence. It does not work at all as soon as we start to deal with large speeds on Earth or large distances in outer space.

Before going directly to $E = mc^2$, would learners be interested to know that long before Einstein came on the scene, nations had a vital practical interest in and competed in discovering more accurate methods for the measurement of time at a distance? That it was vital for military purposes, transportation, and communication? That Einstein spent about five years in a Swiss patent office in Bern reading and judging patent applications on improving measurements of time by clocks? Would students find it interesting to be told how and why not only nations but individual scientists were occupied with the measurement of time? We answered all of these questions in the affirmative, and our experience supported that answer.

There was another part of the story we felt had to be included if the reader was not to be left with the impression that Einstein was a young physicist working alone on a problem that he was able to solve because of his brilliance and creativity. That he was brilliant and creative the reader would accept. But that "alone" leaves out history and its contexts. It leaves out, for example, the very high correlation between war and scientific and technological advances. That was true, in the case of physics, before Einstein and after him. The atomic bomb and nuclear reactors for generating useable energy employed results of Einstein's work. Nor should it go unnoticed that almost immediately after World War II ended the American military was the first agency to publicly express its concern about two things: how the teaching of science in schools extinguished interest in a career in science, and why it was in the public interest to begin to reform schools. In fact, it was the military that began to fund projects by scientists to develop new, more accurate curricula. That this curriculum reform movement was, for all practical purposes, a failure was a consequence of the lack of a firsthand experience of school culture, as well as a total avoidance of any meaningful discussion of the distinguishing features of contexts of productive and unproductive learning. In the half-century since, it is as if no one has learned anything, and in our concluding chapter we discuss our discouragement (to indulge in understatement) about the educational reform initiative of President George W. Bush.

This book has gone through several stages, each of which had to be abandoned as not appropriate for the book format. In the first stage, we prepared a syllabus for teaching $E = mc^2$ to a self-selected group of high school students and one of us (Glazek) spent about four months teaching at one of the best Warsaw high schools. The experience told us that what was intended could not be achieved within a school environment where students have many duties and the system does not allow for extended analysis of issues that students want and need to think about in order to gain confidence in their own reasoning about the issues. Despite these

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difficulties, when at the end of the experience the students were asked to evaluate what they had learned, without exception they wrote that it was “new, new, new.” More specifically, they felt that they grasped some important new points about Einstein’s work, especially about the concept of time. But it was also clear that the environmental pressures to attend to homework and many other school activities did not allow them to study according to our syllabus. The lesson we drew was that the predetermined syllabus was not appropriate for the contemporary classroom. Candor requires that we say that the “teacher” (Głazek) fell into the predictable and understandable trap of bending under the pressure to cover the subject matter, thinking that he had to adhere to the specially designed sequence of topics the syllabus contained.

However, it was not clear to him at that time that the problem was elsewhere than in the syllabus. So, he redesigned the syllabus and went through it over a period of about a year with a group of three self-selected, college-educated adults (two scientists and a teacher of science). The shocking result was that the adults had even greater barriers to overcome in the classroom-like environment than had the high school students. Namely, the adults were constantly concerned about their image in the eyes of others, about how much they appeared to understand. Głazek often observed that adults were not prepared to easily admit to difficulties they had with the subject matter and, primarily, with the interpersonal relationships. These relationships were difficult because the course concerned basic notions such as time and space and, most important, how one thinks about them. An adult running into a basic conceptual difficulty in public feels very unsafe and endangered; in order to preserve status, he or she may choose not to ask questions when a serious difficulty is blocking his or her mind. It became clear to Głazek that the interpersonal relationship between a teacher and a student is essential for the discussion concerning relativity and $E = mc^2$. The experience allowed us, a physicist and a psychologist, to begin talking about issues of education that were no longer focused on the subject matter as much as they typically are. Of course, the same issues were very important between the two of us: one virtually ignorant about psychology and the other about physics.

It turned out that the more we studied the subject from the standpoint of how two minds can or cannot communicate, what are the barriers, and what is required to overcome them, the more we saw how different our frames of reference were concerning almost every issue that came up—far beyond any specific element of the subject matter. Bit by bit, we uncovered to each other—and together—how dramatically different were our starting points and how much we had to go through to overcome the disparity between our frames of reference. The nature of our relationship in writing this book is described in some detail in Chapter 2.

From the initial images of what needs to be done in order to explain $E = mc^2$ and how it should be done—greatly underestimating the magnitude

and type of difficulties one has to overcome—we went a long way, to the point where we understood that the first goal of productive teaching is to create and sustain a relationship of safety and trust in which any and all questions can be articulated. Initially, the subject matter is far less important than a thorough understanding of the relationship between the minds of a teacher and a student.

The question then emerged, How can one explain what matters most in the process of teaching using the book format? A book is not a classroom or a place to meet and talk, ask, respond, ponder, take time to solve a problem, and come up with a solution. The only possibility we found was to tell a sequence of stories.

Speaking very personally and honestly, we were forced to the conclusion that unless and until the distinguishing features of contexts of productive and unproductive learning are understood, evaluated, revised, and the appropriate process of teaching continuously redesigned, educational reform will never see light at the end of the tunnel. One of us made that prediction, orally and in print, in 1965 and in 1990 said the same thing in a book titled *The Predictable Failure of Educational Reform*.¹ Our experience in schools and colleges teaching $E = mc^2$ has not changed our minds about the future. This conclusion is elaborated at length in the last chapter of this book.

Nothing in this book is intended to blame anyone or any group for the failure of the educational reform movement. Educational reformers are well-intentioned individuals who want to improve the outcomes of schooling. And the same is true for teachers, the teachers of teachers, parents, and public officials who feel obligated to do something, almost anything, to improve matters. But all of them are locked into a conception of learning that is self-defeating. The situation resembles attempts to explain the properties of light using pre-Einstein theories of time.

There are a handful of instances where the reformers have employed a conception of learning very similar to what we have written, and they have done this with at-risk urban high school students with inspiring consequences. But these exceptions simply have not and will not spread beyond the confines of their demonstrations for which there is credible evidence, not mere opinions.

Finally, if at the point of a gun we were forced to say in one or two sentences what this book is about, it would go as follows: Just as Einstein destroyed the notion that mass was one thing and energy was another, entirely unrelated, subject matter and the interpersonal context are inevitably and indissolubly intertwined. But the magnitude of difficulties associated with comprehending this statement exceeds the magnitude of difficulties that people usually have with comprehending Einstein's relativity. Our book attempts to explain what this statement is supposed to mean.

The structure of the book is as follows. Chapter 2 explains in an introductory way why and how a physicist and a psychologist came to write a book on the implications for educational reform of Einstein's revolutionary

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scientific contributions. In order to explain what we have to say, we need two basic items of input. One item is a story about the content and meaning of the formula $E = mc^2$, which we tell in this book in a way that we think is most helpful to a person who never had a chance to appreciate what Einstein did. We have studied the problem of how to explain Einstein to high school students, to adults, and between the two of us. On this basis, we attempt to guess what may be going on in the reader's head, and we start from there. This particular motivation does not stem from our assumption, which we do not make, that we know better what the readers do or should think, but it does mean that we cannot be truly helpful by reporting what we have understood without beginning a discussion from issues familiar to the intended readers. As far as a book format allows, we try to build an interpersonal relationship with a reader and use this relationship to create a context of productive learning. However, our main goal is neither explanation of $E = mc^2$ itself nor popularization of science in general. We want to discuss and explain the role of the context of productive learning in educational reform. The example of $E = mc^2$ helps us explain what we mean. But in order to begin from a familiar starting point, we need to show first how an application of the concept of context of productive learning may look in the practice of a school. We need to begin by showing examples of a relationship between a teacher and a student that we have in mind when we speak about the context of productive learning.

Therefore, we begin in Chapter 3, "Mr. Holland's Opus," with a description of the career of a music teacher in a contemporary school. This story is based on a film with the same title, and it illustrates with a number of examples what is involved in a context of productive learning in which the teacher understands the way of thinking of a student and uses this understanding to communicate with the student in a meaningful way, building a context of productive learning in the environment of a classroom, a school, or home. *Our bigger point is that the concept of a context of productive learning is not specific to music.*

Chapter 4 then makes a transition from art to science. We invoke examples from mathematics, astronomy, rocket science, and dancing. Although it is commonly believed that principles of teaching in the case of music must be completely different from principles of teaching in physics, we argue to the contrary and illustrate what we mean with examples. The common assumption that art and science are vastly different, and the related belief that productive learning in art is or should be based on different principles than in science, are most probably a result of the school practice that inculcates such opinions rather than the actual state of the matter. As soon as we make the point about the context of productive learning having basically the same nature in art and in science, we are ready to begin the story of $E = mc^2$.

Chapters 5 to 16 form a carefully arranged sequence of interrelated stories that culminate in the explanation of how the formula $E = mc^2$ comes

about. We attempt to build a collection of images that we consider relevant to the concept of productive learning in the case of $E = mc^2$. The imagery is related to the experiences that we deem familiar to almost every intended reader. One can think that the images and our stories about them form pieces of a puzzle. The reader needs to put the pieces together with our help. We foresee a number of difficulties that a reasonable person may have when trying to imagine and think about the host of problems that Einstein had to grapple with, such as how fast a beam of light moves or what light is made of and how it is seen by different observers.

We hope that by reading the sequence of chapters the reader will eventually become the owner of a set of interrelated, comprehensible, and historically plausible images that facilitate understanding of how a concept of a frame of reference emerges from the need of a human being to precisely describe what happens around him or her. Basically, a carefully built frame of reference is a practical tool for learning about the world, and learning is largely related to a process of building and improving one's own mental frame of reference. By using the story of $E = mc^2$, we can introduce a precisely defined concept of a frame of reference that is used in physics. Then, a concept of a relationship between two frames of reference of two different observers, in physics called a theory of relativity, is discussed. This relationship is used by one of the observers to interpret in his frame of reference the results of measurements that are made and described by the other observer in his own and different frame of reference. Thus, the two observers learn about the same events using their own frames of reference, and they need to understand the relationship between their frames in order to exchange information in a meaningful way. A comparison of their findings in an imagined, tabletop experiment leads to the formula $E = mc^2$. The two observers are called Max and Ming, and it is explained in Chapter 11 why we chose those names.

The key Chapter 17, "Toward a Conception of Learning," takes advantage of the story of Mr. Holland and the story of $E = mc^2$. The chapter combines information from the two stories in order to explain the concept of a context of productive learning as a process that is based on a meaningful exchange of information between a teacher and a student. We use the two stories, what happens in Holland's school and what happens in Einstein's relativity, to show an analogy between them that illuminates the problem of the failure of educational reform.

The formula $E = mc^2$ means that there exists a necessary relationship between the energy E of a piece of matter and the mass m of this piece of matter. The relationship reflects the relationship between frames of reference of two observers in physics. The concept of a context of productive learning means that productive learning of any subject matter is necessarily connected with the interpersonal relationship between a teacher and a student. As the energy E of a body cannot be separated from its mass m , productive learning of any subject matter cannot be separated from the

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interpersonal relationship between a teacher and a student. Our understanding of how $E = mc^2$ comes about originates in the understanding of how frames of reference of two observers are related. The key issue of education is the interpersonal relationship between a teacher and a student, why it needs to be built, how it is built, and how it is used in a process of productive teaching and learning.

The meaning of this analogy requires study for two reasons. One reason is that Einstein's relationship between frames of reference of two different observers of one and the same world of events is not easy to grasp. Einstein discovered the relationship more than a century ago, and the public is still unaware of the content and meaning of his discovery because it is hard to figure out, given the teaching practices adopted in the current educational system. The other reason is that the relationship between frames of mind of a teacher and a student is harder to comprehend than Einstein's theory because the interpersonal relationship between human minds is much more complex than Einstein's relationship between frames of reference of observers in physics. Nobody can tackle outstanding problems of educational reform with lasting success without being prepared for a much greater conceptual effort than Einstein's relativity requires. This is why educational reforms fail, and why they will continue to fail until the relationship between the minds of a teacher and a student is properly recognized and judiciously employed in the process of design and redesign of a self-correcting reform.

The context of learning in a classroom is embedded in the bigger contexts of the educational system and society. The last part of Chapter 17 draws on the stories we tell in the earlier chapters and discusses what reformers need to think about before they engage in attempts to solve the real problem. We explain why the intellectual caliber of the challenges of educational reform vastly surpasses common perception. The challenge is much greater than Einstein ever faced because his considerations were limited to the physics of matter that is not alive and cannot think, feel, or respond to stimuli in the context of its own existence, all these factors determining the result of the teaching that a human being is exposed to. But knowing the magnitude of implications of the formula $E = mc^2$ that followed from a proper understanding of how different observers see the same world in physics, we draw by analogy the conclusion that a proper understanding of the context of productive learning, based on understanding of the interpersonal relationship between the minds of a teacher and a student and on how they see the world and each other, will most probably lead to unimaginable improvement in our educational practice and, hence, also in the quality of our lives.