What is Physics

When my daughter Elena was quite young, I remember her inquiring as to what my profession was. I told her that I was a physicist. Her next question, which, of course, was quite obvious, was, “What does a physicist do?” Without hesitation I responded,“Physics.” Her next question was not so easy to answer. She wanted to know what physics was. Although I do not recollect how I answered her last question, I suspect I mumbled something about the basic structure of the universe, or the laws which govern its behavior, and then quickly changed the subject. The word physics is derived from the Greek word $\phi\upsilon\sigma\iota\varsigma$ whose translation is nature. Hence, physics is the science of nature. Being a science, physics is, therefore, the methodology for studying nature. In this context, physics can be considered a tool for solving problems dealing with *natural* phenomena. I would, however, restrict this interpretation of physics to apply only to problems whose solution, at least in principle, can be expressed numerically. The use of the word nature in the definition of physics may be construed by some as flagrant since everything that occurs is a natural phenomenon (otherwise, it would not occur) rendering this definition of physics impractical, since it includes all phenomena. In spite of its generality there are problems which appear not to fall within the scope of the physics methodology, e.g. determining the meaning of life.[1] Although not applying to all problems, the physics methodology can be applied to solving a broad spectrum of problems which traditionally have not been considered as physics problems. Indeed, physicists study problems in chemistry, biology, economics and finance, and Complexity, an area of study relevant to a variety of topics ranging from the construction of ant hills to the workings of the brain.

Throughout my career as a physicist, the types of physics problems/research which have piqued my interest have spanned the gamut, ranging from problems in traditional areas of physics like quantum theory or relativity to non-traditional areas like economics, finance, or food science. I would now like to discuss in some detail a problem which recently gained my interest. This problem is noteworthy in that it demonstrates how the physics methodology can facilitate solving a problem whose relationship to physics appears to be weak, at best. My wife decided that she would like a lighted walkway, leading from the front porch of our house to the driveway. Furthermore, she wanted the walkway to be constructed of brick pavers. This project was not the typical project to be undertaken by a homeowner lacking experience with projects of this type for a number reasons, including the fact that there were serious drainage and erosion problems that needed to be addressed and that the walkway would be nearly 150 feet long.

The procedure for constructing such a walkway involves preparation of the site where the walkway will be located, involving excavation and leveling of the site and attending to any potential drainage problems. Then, a layer of fabric (geotextile) is laid over area where the walkway will be located. Limestone aggregate, consisting of gravel ranging in size from dust to $\frac{3}{4}$ inch diameter is placed on the geotextile and compacted. Edging, which constrains the pavers from moving, is then secured to the

[1] Actually, it is not universally accepted that the meaning of life cannot be quantified. For example, in the novel *The Hitchhikers Guide to the Galaxy* by Douglas Adams the computer Deep Thought has determined that the meaning of life is 42.

ground through the aggregate. Finally, the pavers, which are full sized bricks, and paver-like lights are placed within the edging on a bed of sand. The joints between the bricks are then filled with fine textured sand. Only the edging and sand keep the pavers from shifting. There is no mortar used. The procedures for constructing the walkway are well-established and straightforward, at least in principle.

Before beginning the project there was a question of deciding what the shape of the walkway should be. It seemed reasonable to assume that a walkway whose direction changed slowly and smoothly would be esthetically more pleasing than one whose direction changed quickly and abruptly. I found that because of the considerable length of the walkway, it was extremely difficult to achieve this effect by sight alone. The primary problem was that although it was possible to construct a walkway with the desired characteristics over sections consisting of short distances, i.e locally, when these smaller sections were considered in total, i.e. globally, the overall shape of the walkway was lacking in the desired esthetics. One solution to this problem was to require that the shape of the walkway be an arc defined by an analytic function, specifically one whose endpoints correspond to the beginning and end of the walkway and whose derivatives exist everywhere between. The solution to this problem is not unique. After surveying a variety of sources of information discussing the types of curves used in landscape design, I found straight lines, ellipses, including circles, and parabolas to be the curves used, primarily. The reason is possibly that these curves are amenable to straightforward geometrical constructions.

An arc of a parabola seems to be especially well suited for defining the shape of a walkway, because some constraints placed on a walkway constitute the initial conditions which uniquely define the arc of a parabola. Typically, the conditions placed on the walkway include the locations where it begins and ends and the direction of the walkway at each of these locations. It can be shown that these conditions are sufficient to define a unique parabola which passes through the two given points with its tangent at each point in one of the specified directions. Thus, I initially chose the parabola to define the shape of the walkway, not only because of the aforementioned reasons, but also because the parabolic shape seemed to provide the necessary bending that was required to circumvent obstacles which prevented the walkway from being straight. Unfortunately, the parabola determined by the conditions applicable to the walkway passed too close to a cluster of trees making it unsuitable for the walkway. Because the general shape of the parabola seemed appropriate for the walkway, I sought a solution which not only satisfied the same initial conditions as the parabola but also allowed one additional initial condition: the specification of another location through which the walkway would pass. This location would be selected as to avoid the cluster of trees interfer-ing with the walkway. One way to accomplish this would be to define a collection of curves parameterized in such a way that for a particular value of the parameter the solution would reduce to the parabolic solution, and for other values the curves would be constrained to pass through specific points. There is no unique way to accomplish this. I decided on a particular solution to the problem based on an analogous physics problem.

A problem presented in introductory physics texts is the motion of projectile under the influence of a constant gravitational field. In this problem the projectile is moving initially, (at time, $t = 0$), with some velocity, $\vec{v}_0$, in an arbitrary direction and under-

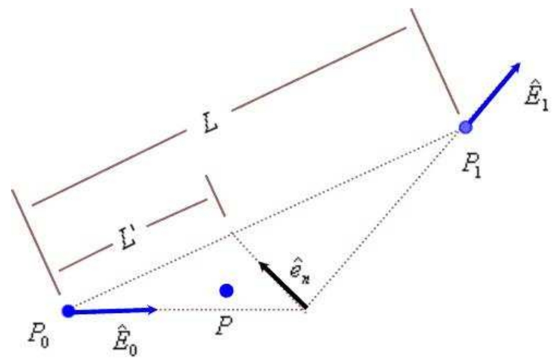

Figure 1: The initial conditions defining the theoretical arc used in constructing the walkway. The points P_0 and P_1 are points where the arc begins and ends. The unit vectors $\hat{E}_0$ and $\hat{E}_1$ are vectors showing the direction of the tangents to the arc at points P_0 and P_1. The point P is the point through which the arc is constrained to pass. The quantity $L' = \frac{n+1}{n+2}L$, where L is the distance between points P_0 and P_1. For a given value of n the direction of the unit vector $\hat{e}_n$ is obtained, as shown in the figure.

goes a constant acceleration, $\vec{a}_0$. It is well known that the trajectory of the projectile is an arc of a parabola. Consider the following generalization of this problem. The projectile is subject to the same initial conditions, but the acceleration, $\vec{a}$, is $\vec{a} = a_0 t^n \hat{e}_n$, where $-1 < n < \infty$, and $\hat{e}_n$ is a unit vector whose direction depends on the value of n, in a way to be given below. The value $n = 0$ corresponds to a parabolic arc. This problem can be recast in a different way, which although less physically appealing, is more amenable to the solution of the walkway problem.

Given three points P_0, P_1, and P on a plane and, in addition, directions specified by the unit vectors $\hat{E}_0$ and $\hat{E}_1$ at the points P_0 and P_1, respectively. It can be shown that for suitable values of v_0, a_0, and n

$$\vec{r}(t) = v_0 t \hat{E}_0 + \frac{a_0 t^{n+2}}{(n+1)(n+2)} \hat{e}_n \,, \tag{0.1}$$

where $0 \le t \le 1$, defines, in general, an arc such that $\vec{r}(0)$ is point P_0, $\vec{r}(1)$ is point P_1, and $\vec{r}(\frac{n+1}{n+2})$ is point P. Furthermore, the tangents to the arc at $\vec{r}(0)$ and $\vec{r}(1)$ are in the directions of $\hat{E}_0$ and $\hat{E}_1$, respectively. The unit vector $\hat{e}_n$ depends on the values of v_0, a_0, and n. In Figure 1 I show the relevant geometry of a typical example.

Application of this theory to the walkway problem is straightforward, in principle. The points P_0 and P_1 correspond to the beginning and end of the walkway. The location of point P is chosen judiciously to avoid the cluster of trees situated in the landscape. The walkway begins at a small, rectangular patio (also constructed of brick pavers) in a direction, denoted by the unit vector $\hat{E}_0$, perpendicular to the patio. The

Figure 2: A section of the completed walkway. Approximately, 95 feet of the walkway is shown. The entire length of the walkway is nearly 150 feet. In the foreground is the beginning of the walkway (point P_0), where it connects to the patio. The point P has been selected so that the walkway passes to the left of the three trees in the midst of the rip-wrap (limestone boulders). The end of the walkway, point P_1, is not shown.

walkway ends at an existing driveway perpendicular to the direction of the driveway. The direction of the walkway at the driveway is denoted by unit vector $\hat{E}_1$. Figure 2 shows approximately 95 feet of the constructed walkway. Figure 3 shows the theoretical fit of Equation 1 to the initial conditions constraining the walkway for the section of the walkway shown in Figure 2.

The final walkway deviates from the theoretical curve because of inaccuracies inherent in plotting a function spanning such large distances over terrain which is not flat. Nonetheless, the final walkway approximates the theoretical curve closely enough to achieve the desired sense of esthetics.

I have shown how physics principles can be applied to solve a problem which traditionally falls outside of the realm of physics. This is an example of what appears to be a current trend: applying the physics methodology to a wide class of problems, not typically thought to reside within the physics domain. A number of years have passed since my daughter questioned me about my profession. My appreciation of what constitutes physics has evolved over the years. Now, if I am asked, “What is physics?” My answer is, “Any problem a physicist attempts to solve.”

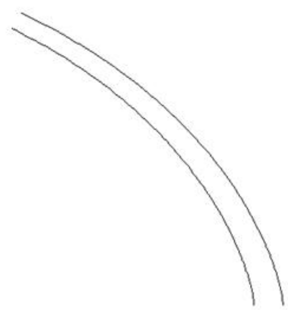

Figure 3: The theoretical arc used in the construction of the walkway. Shown is the theoretical shape of the walkway (See Figure 2.) based on Equation 1. The values of the parameters v_0, a_0 , and n are calculated from initial conditions obtained from measurements made on site.