Ethnic Dance and Physics: Correlations and Possible Implications for Physics Education

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Abstract: Preliminary results of a Dance and Physics Questionnaire sent out in spring of 2006 to members of the international folk dance community support the notion that, for many people, there is a correlation in the way they experience dance, particularly Balkan and contra dance, and physics or mathematics (including engineering and computer science). These results lend support to the idea that education reform which would lead to a more integrated curriculum of science, math, and fine arts would be beneficial, particularly in improving math and physics achievement of students (and K-12 teachers) who may otherwise avoid these subjects.

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Introduction:

There is a small, but growing, body of "non-mainstream" literature coming over the horizon in Physics Education Research, which discusses the benefits of including dance education in formal pedagogy. Seitz (2000, 2002, e.g.) explored the notion that there is a kinesthetic intelligence, difficult to measure, but never the less important for cognitive development, which contributes to the overall academic achievement in children. In the "reverse direction," Kenneth Laws (1992, 2000, 2002) has written about the physics of ballet and the eagerness with which ballet students embrace concepts from Newtonian mechanics, which then help them improve their ballet performance. Laws writes about teaching physics to dancers:

> *" A particularly startling revelation has been to see the remarkable ability of even young dancers to understand the pertinent physical principles. The fact that they can feel these principles working in their own bodies helps them develop deeper insights than others who only read or hear the ideas described or see them demonstrated. It is also often astonishing to see dancers sense, in some deep analytical part of their minds, how to accommodate to near-impossible challenges. And if dancers have not yet learned to fear science, they are open to the benefits and joys of this analytical level of understanding"* (2002.)

The key phrase for physics educators is "*if dancers have not yet learned to fear science…*". In spite of efforts by "mainstream" science organizations such as NASA, The American Institute of Physics, and the national and state legislatures ("No Child Left Behind" Act, e.g.), the fear of physics (and math) is still prevalent, particularly among elementary educators and education professionals. According to physicist and popular author Lawrence Krauss,

> *" The way physicists approach problems, and the language they use, is also removed from the mainstream of modern-day activity for most people. Without a common gestalt to guide the observer, the menagerie of phenomena and concepts attached to modern developments remains disconnected and intimidating. So arises the fear of physics."* (Krauss, 1993, preface to Fear of Physics)

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In a recent editorial in *Physics Today* (July, 2006) the ability of physicists to "imagine new realities" is correlated with what are traditionally considered non-scientific skills, including those usually associated with fine arts (p. 10). Sheila Tobias (Research Corporation, Tucson, Arizona) commented in another editorial in *Physics Today* that the physics education community needs to seek alternate ways of teaching physics to overcome "*America's lagging production of physics majors*" so as to recognize a talent for physics that is "*differently packaged from the norm*" (August, 2006, p. 10).

Standards for dance and music exist in grades "K-12" in the National as well as California Educational Frameworks, yet very few public schools have time, resources, or qualified teachers to implement them. According to the California Arts Framework, adopted in 2001 for grades 9 – 12, the section "*Connections and Applications Across Disciplines*" states that students should "*Compare the study and practice of dance techniques to motion, time, and physical principles from scientific disciplines (e.g., muscle and bone identification and usage; awareness of matter, space, time, and energy/force)*" (p. 35).

European and American educators from the nineteenth and early twentieth centuries advocated for such an integration (John Dewey in the United States and Johann Pestalozzi in Switzerland, for example). Michael D. Higgins, the former Irish Minister for Arts is quoted on one website from the New Zealand Ministry of Education as saying,

"*Once the arts are restored to a more central role in educational institutions, there could be a tremendous unleashing of creative energy in other disciplines too.*" (http://www.leading-learning.co.nz)

While standard public education in most (western) countries is remarkably stratified, arts and sciences rigidly separated, and very little money and attention are actually given to arts education in the public sector, the participation in dance at all levels in American society has continued to increase. On an informal, anecdotal level, it has been noticed that a great many people in the United States who are involved with music and dance on a non-professional but "serious amateur" level are also involved in professional fields that involve math, engineering, or physics. Several studies support these popular observations.

In 1985, Canadian teacher, researcher, and dance ethnologist Yves Moreau conducted a survey of "recreational" folk dancers in the United States, Western Europe, and Japan in an attempt to understand the interest in Bulgarian music and dance that has been steadily growing outside of the Balkans, since the middle of the twentieth century (Moreau, 1990). Over three hundred people from twenty six states, five Canadian provinces, and twelve countries responded to his survey, and of that population, thirty six percent reported that their professions were in the scientific domain of engineering, mathematics, physics, or computer science.

Melissa Miller, an American scholar in Balkan and Middle Eastern music and dance, who is also a clinical psychologist in Mountainview, California, did a similar survey of 121 people at the Mendocino Woodlands Balkan Music and Dance Camp in July, 1994. Miller found similar figures to those found by Moreau in Canada: more than 53% of the men and 23% of the women reported professions in science or engineering. She also found a disproportionately large number of campers in education fields, most teaching at the secondary or higher levels. In all, she found 76.5% of the women and 86.7% of the men reported having professions in science, engineering, or education (Miller, 1994).

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At Stanford University, professor of Social and Vintage dance Joan Walton noted that, while 23% of the student population at Stanford was in the School of Engineering, 52% of the students in her Social Dance course had majors in Engineering or related sciences, while 60% of the upper division students who were in the advanced performing ensemble were engineering majors (Walton, 1998). (It is also of interest to note that the director of the "Vintage Dance" ensemble of Stanford University, Richard Powers, an internationally-recognized scholar of western social dance forms, holds a degree in mechanical engineering, and several patents!)

A study of science students at Harvard University (Nikitina, 2003) revealed that, although dance and math and sciences are taught separately, students' experiences of each discipline are deeply connected. Nikitina, researcher with Project Zero, suggested that a close examination of the of the experiences of students in both performing arts and science courses could provide insights for bridging the gaps between academic areas. Students in her study reported benefits of studying dance that included learning to see math as a creative channel with its own intuitive processes, and doing better in difficult classes such as physics, when academics were balanced with dancing every day.

It seems quite plausible, then, that the integration of dance and traditional academic instruction in physics and math would be beneficial to a great many students, and should therefore be further investigated. To support this idea, an email survey was sent to three mailing lists of people who maintain an active interest in recreational dance, looking for people who hold careers in physics-related fields. The results of the "Dance and Physics" survey of Spring, 2006, are reported here.

Dance and Physics Survey:

This study reports the preliminary results of an email survey sent out in Spring, 2006. The survey went to the following lists: Santabarbara-folkdancers@yahoogroups.com; eefc@eefc.org (East European Folk life Center, international mailing list, hosted in northern California); www.balkanfolk.com (International mailing list for Bulgarian folklore, hosted in Sofia, Bulgaria). Rather than sending the survey as an attachment, email was sent out soliciting volunteers who were interested in filling out my survey. Forty six people responded to the email entitled, "Dance and Physics Survey." The names were removed from the surveys as they were received, as were the email addresses, and the responses were saved as "Word" files, each with an identifying number, in the order in which they were received. While these data are not exhaustive, they support the survey results of Moreau (1990), Miller (1994), and Walton (1998), as well as the anecdotal reports of Laws (2000, 2002), that there indeed is a correlation between the learning and experiencing of dance and physical sciences (physics, math, and engineering) for many people, which is more than mere coincidence.

Data:

1. Ethnographic distribution: Two thirds of the people who responded live inside the United States, and are American, of European descent. Eight percent are Bulgarian, living in Bulgaria; four percent are Western European, six percent East European (other than Bulgarian), six percent "Other Balkan" (Turkish and Greek), and one person was from China. A number of people reported their ethnicity as "Jewish," however since this can be arguably considered a religious rather than ethnic category, I have not distinguished between Jewish and non-Jewish Americans of European descent.

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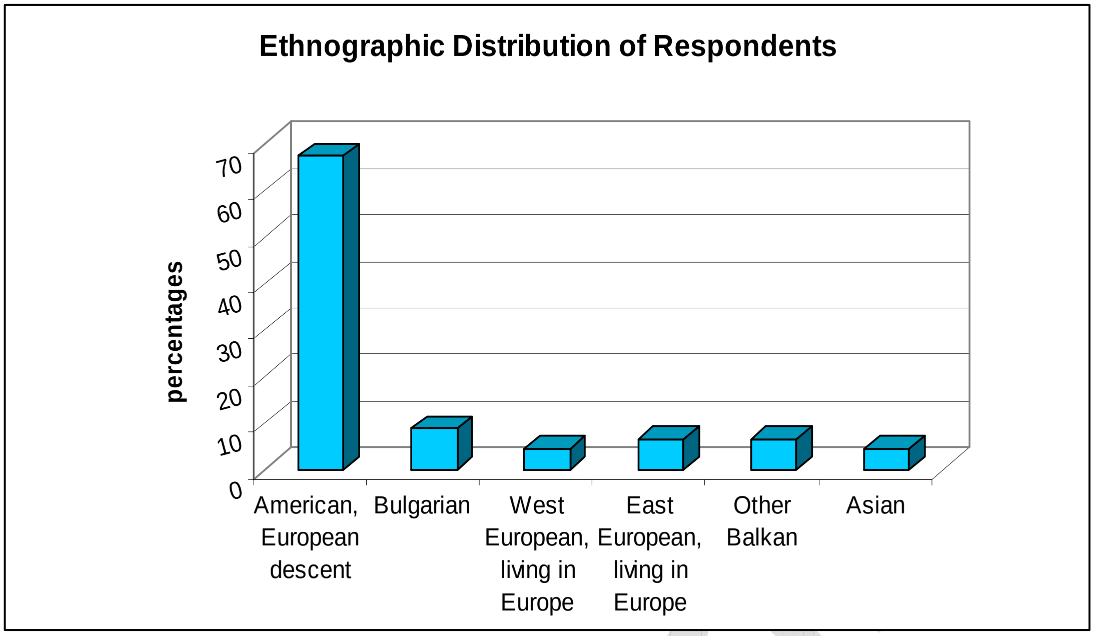
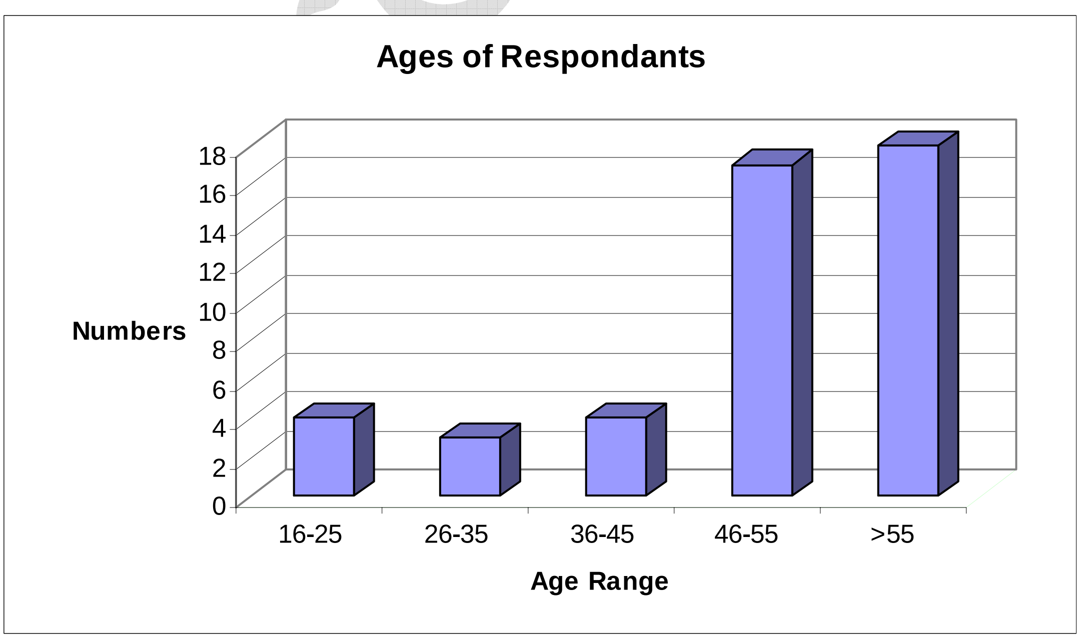


2. Ages of respondents: Three quarters (76 %) of the respondents were over 46 years of age, a result which is consistent with the anecdotal observation that there is a shortage of young people who are interested in folk dance in recent years. In Moreau's (1990) survey, which he conducted in 1985, the average age of the respondents was 36. In the present survey, seven out of forty six reported their ages as under 36; of these, only one (in the 26-35 range) is American, of European descent, presently living in the US. Five are Bulgarian, Romanian, or other East European, and one (in the 26-35 category) is Indonesian, living in Jakarta.



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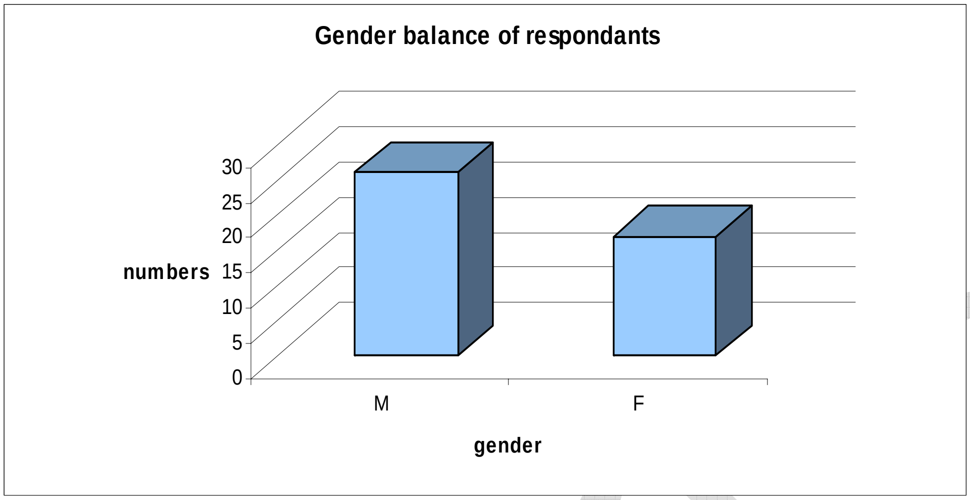
3. Gender of respondents: More men than women responded to this survey (60.5% : 39.5%, or 1.5:1) . One possible reason is that, since more men than women still participate in physics-related fields, and the title of the survey was “Dance and Physics Questionnaire,” women may not have been as inclined to respond.



4. Fields of endeavor. Nearly 60% of the respondents said their fields are physics, chemistry, engineering, math, or computer science. This includes those who said they are currently retired, and those who are currently students, and those who had multiple fields, such as science and business (as in engineers who ran their own businesses). This figure is somewhat higher than the 36% found by Moreau (1990) in his 1985 survey, perhaps in part due to the difference in gender balance between his survey and the present one: in Moreau’s survey 51% of the respondents were female, as opposed to only 39.5% female in this survey.

Only six of the respondents in the present survey said they work in dance or music as professionals; the rest are recreational dancers, most of whom said they do some performing without pay, and some teaching for recreational groups with little or no pay. Of these six, four are American; one is a dance professor at an American university, and one earns 100% of her income by teaching recreational groups. Two were professional Middle Eastern dancers, both currently enrolled in Ph.D. programs in science-related fields (psychology and physics). The other two are European.

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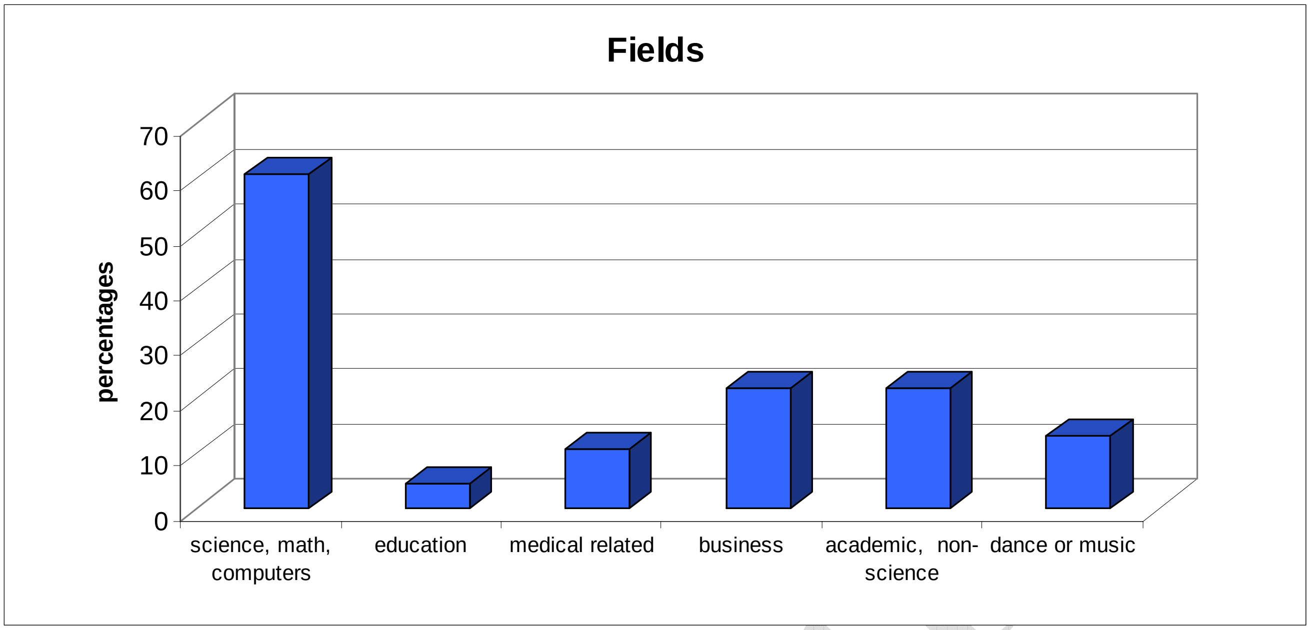

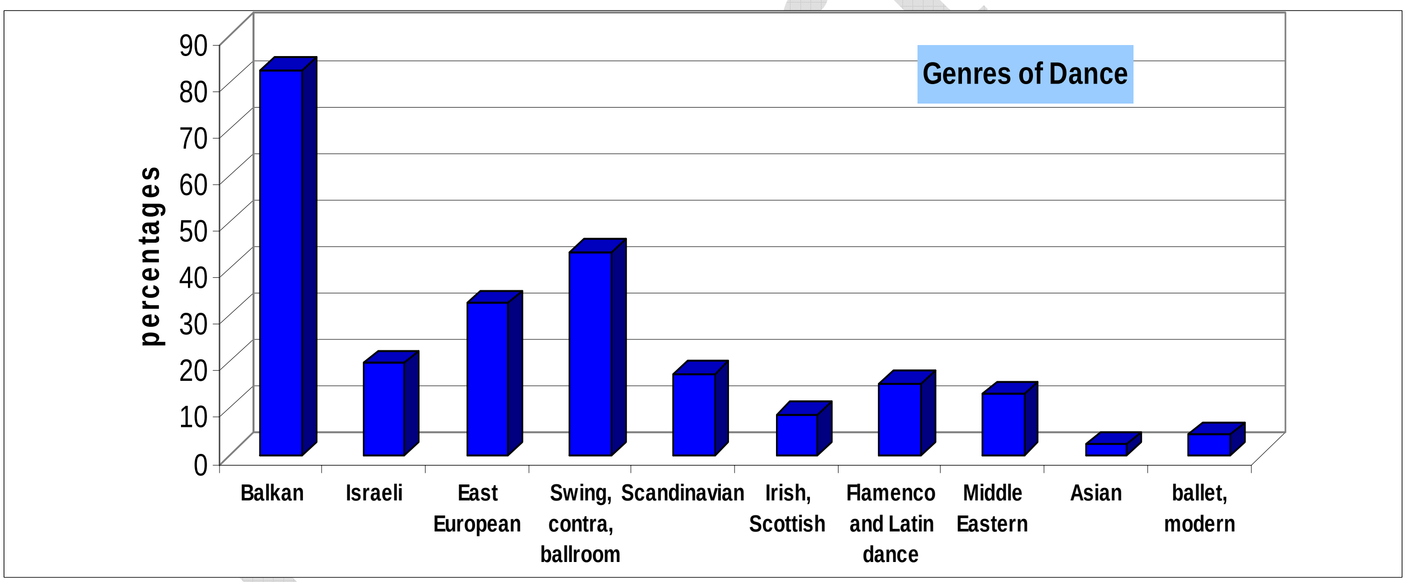

5. Preferred genres of dance. Most of the respondents said they practice Balkan or international folk dance. International folk dance (IFD), among American folk dance groups, usually means "mostly" Balkan dance (Bulgarian, Macedonian, Greek, Serbian, Turkish, and Romanian), with "some" Scandinavian, Scottish country dance, and "traditional" Israeli. Some people specified a preference for other-than-Balkan styles. Somewhat less than one fifth said they also do American social forms such as contra dance, ballroom, and swing. A few specified salsa or tango, and one said Flamenco.

6.. Factors that influenced initial attractions for dance and physics More than half - 54% - of the respondents said that they were inspired to start dancing by friends or family, including friends in college who attended folk dancing, family members who danced, and a need for social activities, while 33% said they were inspired by an inspirational teacher. (The famous American

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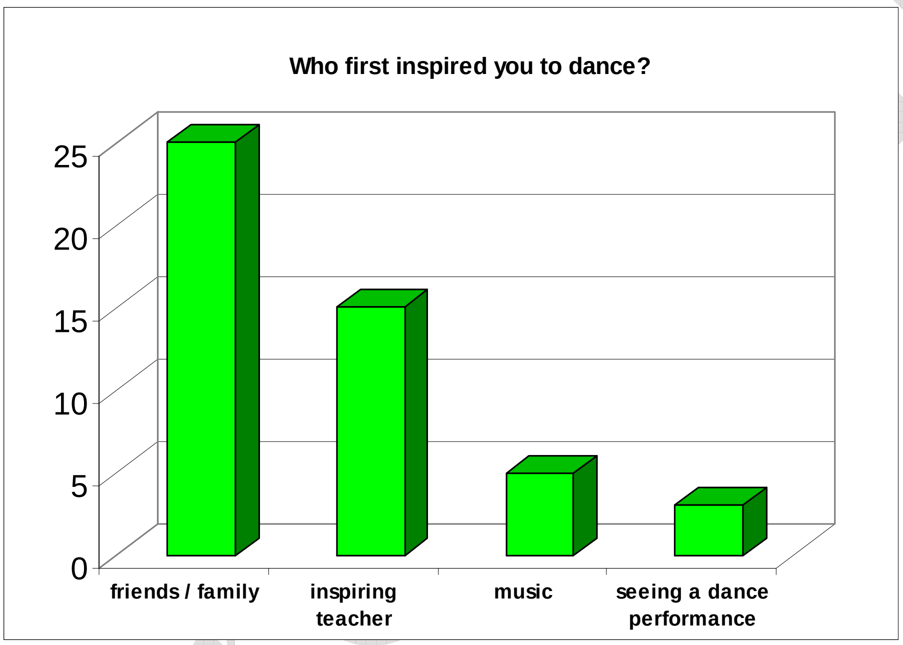
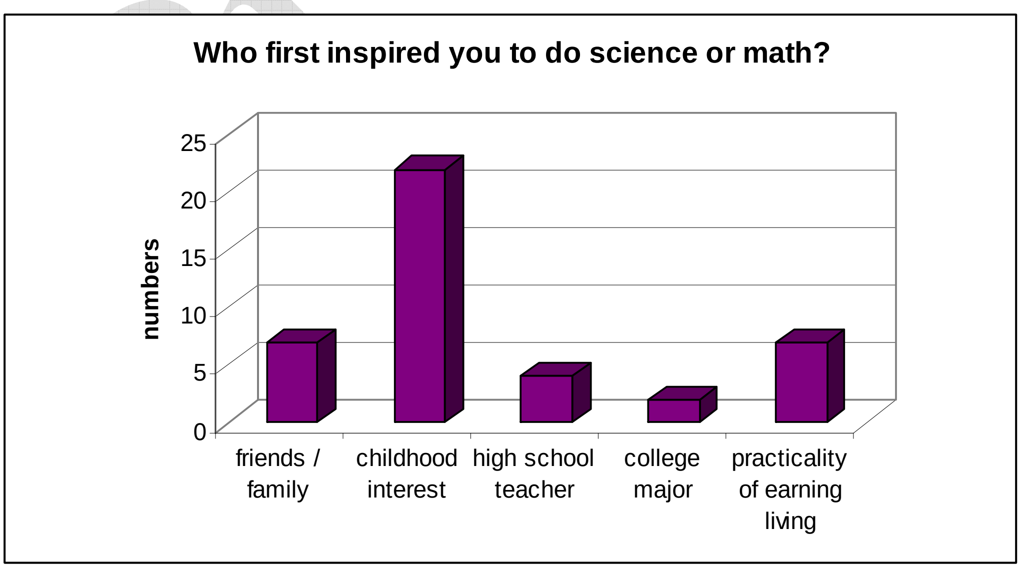
folk dance teacher who was most often mentioned was the late Dick Crum.) On the other hand, 48% of the respondents said that their interest in math and physics came from a childhood interest. 15% said they were inspired by friends and family, mostly by parents, uncles, grandparents, and in one case an aunt who was an engineer. Only 8.7% said they were inspired to pursue math/physics by a teacher in school, and 15% by the "practicality of earning a living." In fact, several people alluded to poor teaching in school that caused them to turn away from math or physics, even though they had had an innate interest in the natural world and mathematics as a child. One respondent wrote:

> *"Time, and the enigma of an infinity of infinities started to fascinate me by age 14, but the brutal way math was taught at my school left me with no understanding."*





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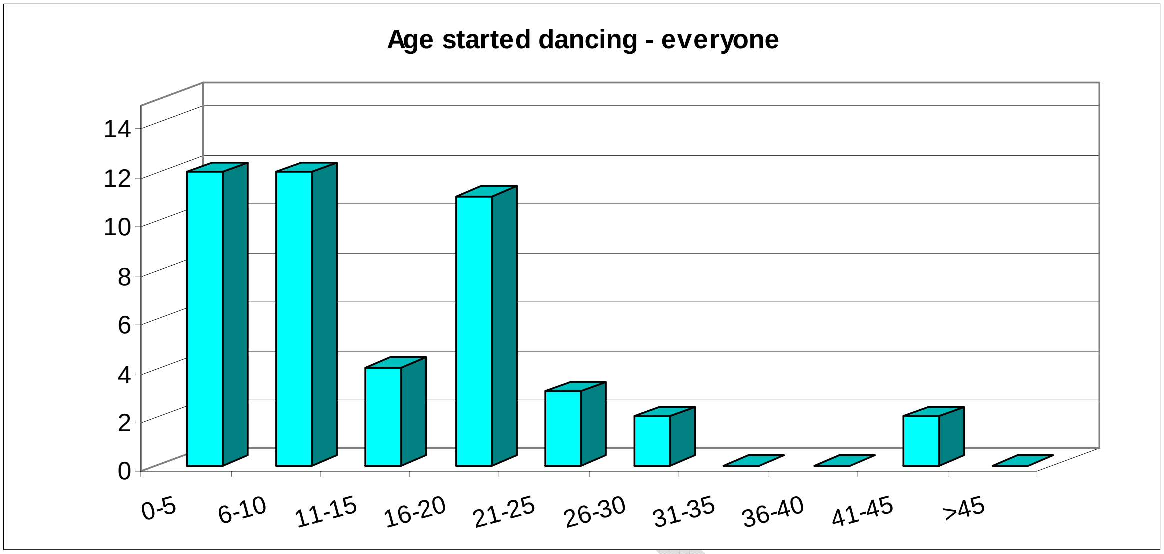
7. Age when started dancing:

There appear to be two main entry-level age ranges when people started dancing: sometime in elementary school, age 10 and younger, and then in sometime in late high school to early college, between ages 16 and 20.



When separated into male and female categories, it appears that for both males and females, more people started dancing in elementary school, however men's interest in dance seems to have peaked again at the 16-20 year old range, and again in the 41-45 year old range, (perhaps correlating with a natural interest in cultivating social relationships during key life stages).

The trend that more women start dancing at a younger age than men suggests that using dance and music to teach physics and math, particularly in the elementary grades, may indeed have a very tangible positive effect on improving the participation of women in math and physics-related fields later in life. Regardless of the respondents' initial reasons for their interest in dance, from their comments (quoted in the next section), it is clear that there is a strong correlation between their interest in patterns, puzzles, and symmetry in math and physics, and their attraction to music and dance, particularly Balkan dance. Indeed, affinity for patterns is one of the most common reasons cited for their attraction to this form of dance and music.

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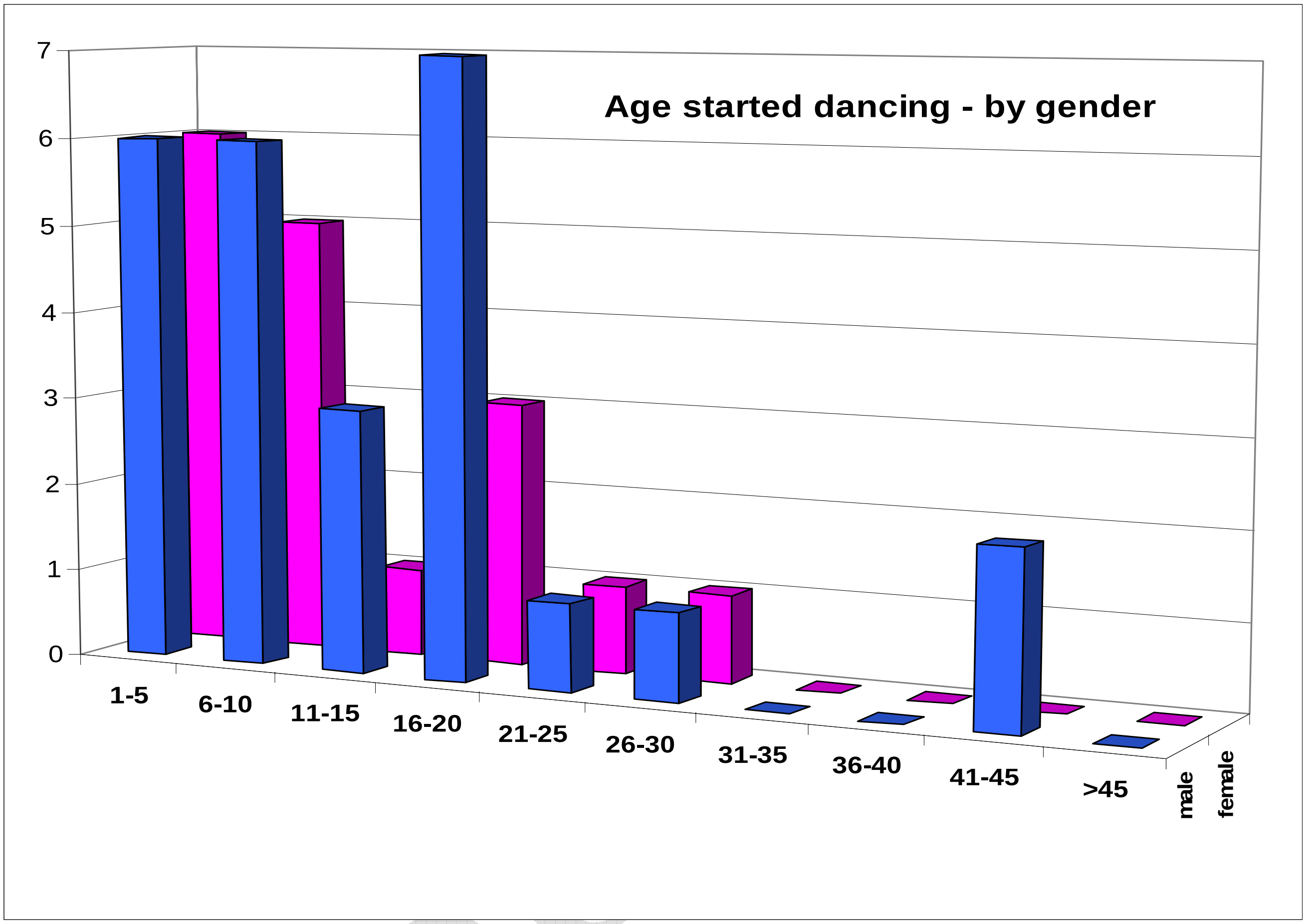

8. Individual quotes. The following quotes are excerpted from the responses to two of the questions:

> *19. Are there similarities in how you approach a problem in physics and a choreography in dance? and*
>
> *20. Are there similarities in the way you experience dance and physics or math?*

The answers to these appeared very similar; in fact, some respondents said “see my previous answer,” hence the responses are reported together. These responses support the hypothesis that there is a correlation between people’s experiences in science and dance. In addition, these data also support the results of Mihaly Csikszentmihalyi (1990, 1996, 2001) that the experiences of “doing” math or physics, and dance, can produce a “flow” experience for the individual.

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Summary of responses to the questions:

<u>Are there similarities in how you approach a problem in physics and a choreography in dance? and Are there similarities in the way you experience dance and physics or math?</u>

- *visualization and imagery*
- *break them down into manageable pieces*
- *experiencing patterns*
- *I become extremely focused on what I am doing, and tend to lose my awareness of the rest of my life.*
- *similarities between dance and language, the language of math*
- *same feeling as solving a problem – it is about spatial relationships, the essence of math*
- *approaching a problem in 4 dimensions*
- *dance allows my talent for math to be part of my social life*
- *seeing patterns, hearing rhythms*
- *In addition to thinking visually, I tend to think kinesthetically about engineering problems.*
- *A neat solution to a problem is like a dance that fits the music well.*
- *There is a kind of magic that happens when you put it all together with the music that is similar to a research problem. You break it down into pieces and then the flash of insight comes when you identify new relationships.*
- *There is beautiful symmetry in music, math, physics, and dance. Dance and music in the Balkans is the abstract brought to life, the spirit of the subtle nature of complex rhythms and musical themes manifested in an audio form that gives us an opportunity to move with it and experience it directly. Applied physics in a way.*
- *patterns, of course!*
- *jazz and math; dance is an expression of music, and math expresses physics.*
- *English country dancing would benefit high school math students, as there are wonderful mathematical permutations that would inhabit students' bodies and make math easier.*
- *By temperament I feel I share a lot with the many male folk dancers who prefer to express their creativity within a known and consistent framework. I believe this parallels that large part of the scientific and technical enterprise in which work is based on established and trusted theory.*
- *Patterns and structures are truly fascinating, and both physics and dancing have plenty of that.*
- *a strong sense of connectedness to musical phrases and physical experience of movement, a trance-like nuance which can also happen with applied science and hands-on problem solving*
- *Symmetry in physics is one property which is very important, and in dancing it has a super importance also.*
- *total immersion; pattern recognition; totally absorbing*
- *commonality of spatial relationships between ballet and science*
- *In Balkan folk dance it is the complex dance sequences and odd beats that are challenging as math/physics problems are.*

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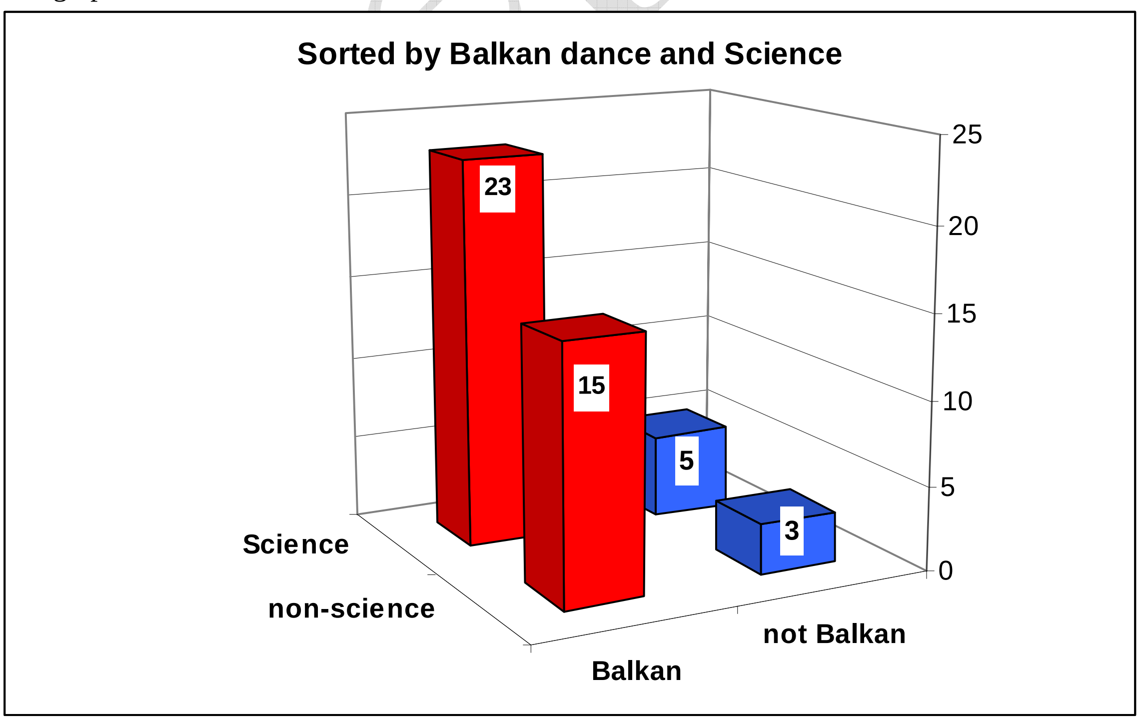
Discussion and Analysis.

Only five out of 46 people said there was no similarity for them between dance and music on the one hand, and math and physics on the other. All five are in the over-46 age category; four are male, and one is female (>55 category). The one over-55 female who said there is no similarity for her, reported that she began dancing at age 28, currently works teaching Balkan dance to recreational groups, and describes herself as “passionate” about dance. I believe this person is anomalous in the sense that very few people who start dancing when they are nearly 30 actually evolve to the point of earning a living at dance. Thus, this person is exceptional. One male respondent spoke extensively of his attraction for dance as a way of relating to women and experiencing closeness with women in a socially acceptable way. While both men and women may experience this “benefit” as a result of partnered social dance forms, his answers should be discounted as also anomalous, and completely irrelevant to the question at hand. Thus, there are only three older males out of this population, who do both physics or math and dance, who report no connection for them between sciences and arts.

Balkan dance and Science. Balkan dance is characterized by interesting patterns in time, marked by the feet, while the spatial pattern is a simple circle, or open circle, line, or if the line is long, it curls into a spiral. The temporal patterns, particularly in Bulgarian and Macedonian dance, are created by the asymmetric rhythms in odd time signatures, such as 5/8, 7/8, 9/8, 11/16, 13/16, 15/16, 18/16, for example, which are broken into patterns of 2 beats and 3 beats. These asymmetric patterns form a rhythmic puzzle which is appealing to people who report an interest in puzzles, patterns, and symmetry.

Twenty-three people, or nearly half, of the respondents work in a science-related field *and* practice Balkan dance. Fifteen people, or one third, practice Balkan dance but work in a completely non-science field. Five people in science-related fields practice some dance form other than Balkan, and three people practice neither science nor Balkan dance, as displayed in the next graph:



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Observed	Science	non-science	totals
Balkan	23	15	**38**
not Balkan	5	3	**8**
	28	**18**	**46**

Among this population, 23/28, or 82% of the people who work in science-related fields also enjoy Balkan dance, and 5/28, or 18% of the people in science-related fields prefer another genre of dance over Balkan. 23/38, or 61% of the people who enjoy Balkan dance work in science-related fields, and 15/38, or 39% of the people who enjoy Balkan dance work in non-science-related fields. Thus, from this survey, it would appear that people who work in science and math-oriented fields are likely to enjoy Balkan dance, and people who enjoy Balkan dance are likely to work in science-related fields.

In this sample of 46 adults, regardless of occupation, 38/46, or 83% of the population enjoy Balkan dance, and 17% prefer another genre; regardless of dance preference; 28/46, or 61% of the population works in a science or math-related field, and 39% work in a non-science field. The percentage of people in this survey who work in science related fields is more than twice as high as a general population of professionals in the United States. According to the United States Census Bureau reports for 2000, available on line at http://factfinder.census.gov, among professional adults, 27% work in fields related to science (life and physical), math, architecture, computer science, and engineering, while 73% work in non-science related fields of social and legal services, health care, education, and the arts.

To understand whether there is a real correlation between people who have professions in math or science-related fields and people who like Balkan dance, let us take the census proportions, and say that in any random sample of professional adults, we can expect 27% to work in science, math, engineering, or computer-related fields, and 73% to have professions in non-science fields. Then we should expect that, out of a random sample of 46 professional people, 12 would be in science or math-related fields and 34 would be in non-science fields. If we adopt a null hypothesis that there is no correlation between an affinity for Balkan dance and science or math, then we can compute the frequencies in our population of 46 dancers whom we expect to work in science or not as $\frac{nBalkan \times nScience}{total}$ where *nBalkan* = (38, 8) representing the number of people in the survey who prefer Balkan dance and those who prefer another genre of dance, regardless of their professions, and *nScience* = (12, 34) representing the expected numbers of people in the survey in science-related and non-science-related professions, *if* the people in this survey followed the national averages, according to the U.S. census of the year 2000.

Expected	Science	non-science
	12	**34**
Balkan	10	28
not Balkan	2	6

Thus, if our population followed the census proportions, then of the 38 who prefer Balkan dance, we would expect 10 to be in science-related fields and 28 to be in non-science fields; of

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the 8 who prefer other genres, we would expect 2 to be in science-related fields and 6 to be in non-science fields.

Observed	Science	non-science	Expected	Science	non-science
Balkan	23	15	Balkan	10	28
not Balkan	5	3	not Balkan	2	6

If we assume a null hypothesis that there is no correlation between having an aptitude for science and math and having an affinity for Balkan dance, we can compute a χ^2 statistic:

$$\chi^2 = \sum \frac{(Observed - Expected)^2}{Expected}$$

We find that $\chi^2 = 28.9$, which is much greater than the critical value of 10.827 for one degree of freedom and $\alpha = 0.001$, or the probability of finding such a large χ^2 is less than 0.001. A look at the individual χ^2 cells shows that the greatest contribution comes from the Balkan + Science cell:

chi^2	Science	non-science
Balkan	16.9	6.035714286
not Balkan	4.5	1.5

In summary: By choosing the expected numbers of people in science and non-science related professions from the national averages, the assumption is that *any* random sample of 46 people, regardless of recreational activity, should approximately follow the national averages. Therefore, *if* the dancers in this email survey followed the national averages for professionals in science-related and non-science related fields, then we should find approximately the same proportions of science to non-science professionals as the national averages. The χ^2 statistic should be small. A χ^2 of 28.9 for 1 degree of freedom [1] tells us that there is less than 0.0001% chance that there is no correlation, or that people with an aptitude for science and math do show an affinity for Balkan dance. (See Appendix A for further explanation.)

The question is: If people who do well in science report that their participation in Balkan dance is satisfying in ways that are similar to their experiences in math and science, can we as educators use the principles of symmetry and patterns in Balkan music and dance to teach principles of symmetry and patterns, proportional reasoning, and spatial relationships, which are so are important in math and physics, and with which many people have difficulty, *as these principles are traditionally taught in school.* These data, taken in context with other research on bodily-kinesthetic intelligence (Seitz, 2000, e.g.), the reports by Kenneth Laws (2000) on teaching physics to ballet students, and the reports from major universities such as Stanford and Harvard discussed in the introduction, imply that it is possible Particularly useful are music and dance forms that rely heavily on patterns, puzzles, and symmetries, such as Balkan dance.

[1] df = (# rows -1)(# columns -1) = (2-1)(2-1) = 1

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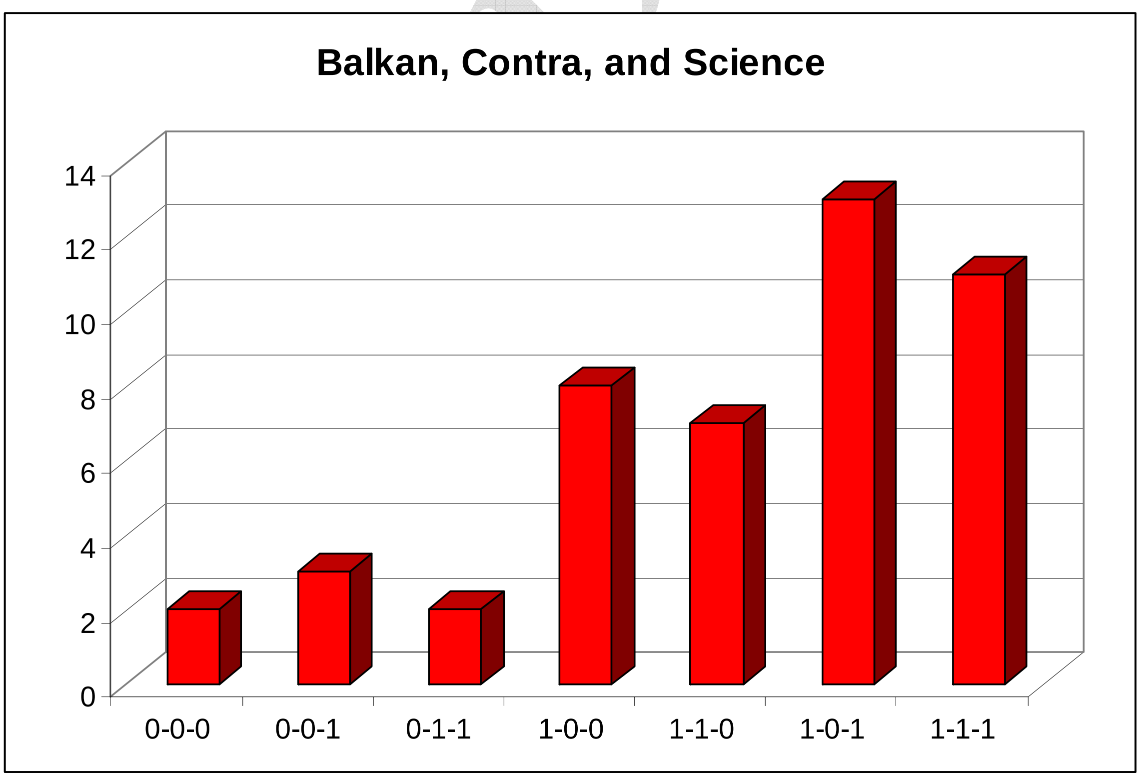
Contra dance, Balkan dance, and science. A number of people commented on the pleasing aspects of symmetry in patterns of contra dance and math. Contra dance, while being based rhythmically on a very simple 4/4 time signature, is based on intricate circular patterns in space that are accomplished by two long, gender-balanced lines of dancers, of equal length, weaving in and out in various permutations, always returning "home" at the end of each pattern. There is a pronounced adherence to principles of symmetry and balance in the contra dance form, and it is a highly structured framework which leaves only a little room for individual improvisation. The vast majority of people in this survey enjoy either Balkan, or contra dance, or both.

A separation of the sample population into categories of Balkan, contra dance, and science, showed that the greatest number of people prefer Balkan only or Balkan and contra dance, together. For ease in counting, I wrote a small program in Visual Basic to sort and count the occurrences of 1's and 0's, and sort according to the three categories "Balkan," "contra," and "science." The counts for each category are displayed in Table 1, and displayed in the following graph. For example: "0-0-0" indicates that a person is not in a science-related field, and prefers a genre of dance that does not include either Balkan or contra; "1-1-1" indicates a person in a science-related field who enjoys both Balkan and contra dance.

no Balkan, no contra, non-Science	no Balkan, no contra, Science	no Balkan, contra, Science	Balkan, no contra, non-Science	Balkan, contra, non-Science	Balkan, no contra, Science	Balkan, contra, Science
0-0-0	0-0-1	0-1-1	1-0-0	1-1-0	1-0-1	1-1-1
2	3	2	8	7	13	11



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Taken together, the correlation between people with professions in math or science related fields and an affinity for either Balkan or contra dance, or both, is even stronger than for Balkan alone. Of the 28 people in this survey who work in science or math-related professions, 26 enjoy Balkan AND/OR contra dance.

Observed	Science	non-science	totals
Balkan +/or contra	26	15	**41**
Balkan nor contra	2	3	**5**
totals	**28**	**18**	**46**

Again, using the same population frequencies from the 2000 census of 27% science-related and 73% non-science related professions, we can compute the expected occurrence in a random sample of 46 people who enjoy Balkan and/or contra dance who work in science or math-related professions:

Expected		Census Sci.	Census non-sci
		12	34
Balkan +/or contra	**41**	10.69565217	30.30434783
Balkan nor contra	**5**	1.304347826	3.695652174

Then, by comparing the computed expected frequencies of science or math professionals among a random sample of 46 people who enjoy Balkan and/or contra dance, with the actual frequency found in this sample,

Expected	Sci.	non-sci	Observed	Science	non-science
Balkan +/or contra	11	30	**Balkan +/or contra**	26	15
Balkan nor contra	1	4	**Balkan nor contra**	2	3

we can again compute a χ^2 :

χ^2	Science	non-science
Balkan &/or contra	20.454545	7.5
not Balkan nor contra	1	0.25

and we find a total χ^2 statistic of 29.2. By the same reasoning as in the previous section, it seems that there is indeed a correlation between people who have an aptitude for science and math and an affinity for Balkan and contra dance, which rely heavily on symmetries and patterns in time and space.

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Implications for education. The trends that emerge from these data support the results of previous studies, indicating that indeed there is a strong correlation between a preference for logical thinking that is manifest in physics, mathematics, engineering, and computer science and an enjoyment of music and dance. As this sample, as well as the other studies referenced here, sampled mostly Euro-American western people, the genres of dance and music mentioned were Balkan dance and music, contra dance and social dance, and ballet. There is no reason to believe that Balkan and contra dance are necessarily the *only* genres through which principles of math and physics can be taught. These genres can be expected to "work" for the people of the cultures in which these forms are indigenous. There is every reason to believe that the dance and music of any culture can be utilized to introduce concepts from math and physics effectively. For example: Middle Eastern, Afro-Brazilian and West African music and dance, as well as Flamenco music and dance, are quite popular in California among a wide variety of people. The rhythmic structure of much of the music from the Arab world and former Ottoman Empire shares much in common with Balkan music; African dance relies heavily on principles of kinematics and dynamics, and Flamenco utilizes intricate rhythmic patterns.

Dance and music exist in every culture, and offer natural channels to understand symmetries, patterns, in a natural, intuitive, and bodily-kinesthetic way. Thus it seems logical to test whether educators can utilize people's natural attractions for music and dance to make math and physics accessible to a wider population of students. In addition to classical Newtonian kinematics and dynamics, which are typically addressed through curricula which involve the physics of sports, principles of symmetry and spacetime can be addressed through music and dance, which relate to many topics in classical as well as modern physics, in addition to classical Newtonian kinematics and dynamics.

This correlation between science, math, and dance may be especially important in reducing the "gender gap" in physics, since it is observed that more girls start dancing at a young age (when more boys are getting interested in science). Thus, these data suggest that, by developing a broader "learning bandwidth" for comprehending the logic of math and physics through aesthetic channels of music and dance, it may be possible to engage girls' interest in the sciences at a young age. Curriculum development and testing should definitely be pursued in this regard.

Perhaps the greatest benefit of an integrated physics and fine arts curriculum will be found not simply by utilizing dance directly to teach principles of physics, but in the environment of creativity and imagination that such an integration affords. In a recent editorial in *Physics Today* (July, 2006, p. 10) the ability of physicists to "imagine new realities" is correlated with what are traditionally considered non-scientific skills, including those usually associated with fine arts, such as playing, imagining, pattern forming, and harmonizing. Especially now, in the light of the new developments in eleven dimensional String Theory and the overwhelming evidence for dark energy with "negative gravity" – concepts that go beyond General Relativity and Quantum Mechanics of the 20th century – the importance of creativity in physics is gaining recognition. Sheila Tobias (Research Corporation, Tucson, Arizona) commented in another editorial in *Physics Today* that the physics education community needs to seek alternate ways of teaching physics to overcome "*America's lagging production of physics majors"* so as to recognize a talent for physics that is *"differently packaged from the norm"* (August, 2006, p. 10).

The implication of this study for educators, then, is to help students develop an early interest in the "languages" of music and dance, and to recognize patterns and symmetry in the world around them, which will then help them access the "world" and "language" of math and

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physics. Teachers can then tap into this natural human affinity for patterns and symmetry, to introduce math and physics though the channels of music and dance, in a less threatening, more naturally familiar, environment.

This study supports work that has already been written on the value of dance in academic education (Seitz, 2000, 2002), the use of physics to teach ballet (Laws, 2002), and the benefits of using music to teach math in middle school (Bamberger and DiSessa, 2003). Case studies of exceptionally creative people have highlighted the similarities in the creative process for famous artists and scientists (Wallace and Gruber, 1989; John-Steiner, 1997, e.g.), however there is still a need for a formal study in the "average" classroom to demonstrate that these similarities are indeed widespread, the norm rather than the exception, and ought to be encouraged for more effective education. The strong correlations that have emerged from this preliminary study indicate that testing of integrated physics and fine arts curricula is warranted.

A larger population will be interviewed and surveyed, including recreational dancers from a wider variety of dance genres, college students in physics and dance, and elementary school teachers and teacher trainees. A revised introductory physics curriculum that is based on symmetry and the conservation laws is being developed, which lends itself more naturally to an integrated approach of physics and fine arts than the current "fragmented" curriculum. Modules on physical dimensions, the nature of spacetime, motion, patterns in math and music, numbers in nature, and dynamics of dance are being written, which will be tested with students at the University of California, Santa Barbara, during the winter of 2007.

In conclusion, it is important to note that the cultural imperative of expressing oneself through the folklore of one's culture, as well as the importance of learning and appreciating other cultures, can best be satisfied by integrating dance and music into an academic environment (Reed, 1998). Thus, there is an even more profound benefit from integrating dance into traditional academics than simply improving science and math education, that relates to all areas of humanities, as well as teacher preparation. Possible fields of study include:

- the cultural significance of dance as discourse;
- dance and the co-construction of gender identities;
- correlations between dance and colonialism and cultural hegemony;
- dance and political expression / repression

Socrates is reported to have said that one is not truly educated until one has learned to dance. Perhaps it is time we take his words to heart!

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Appendix A: Calculation of probability for χ^2

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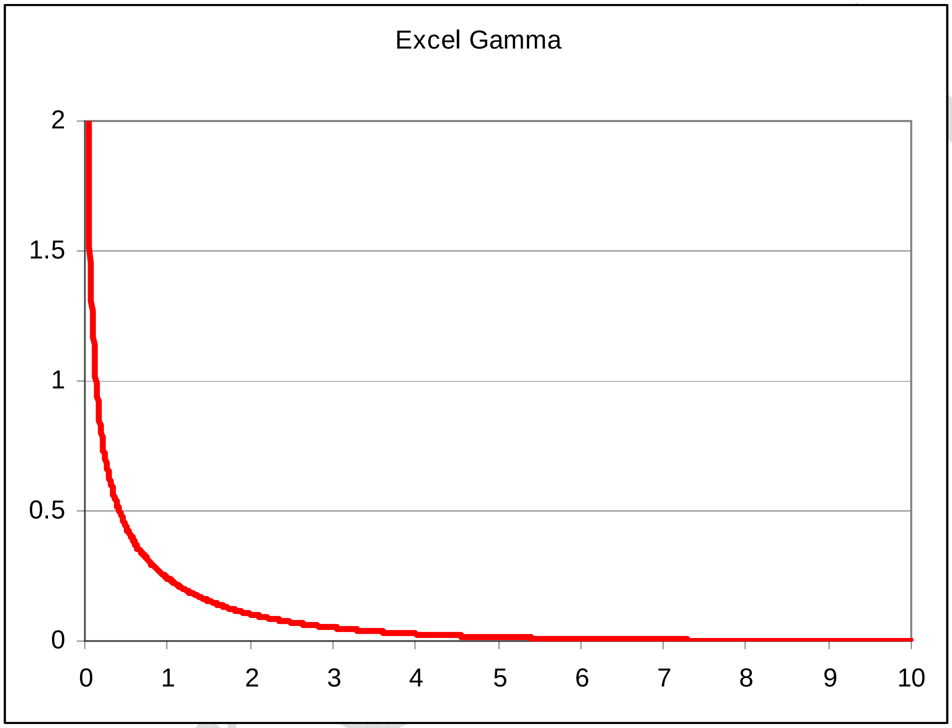
$$f(\chi^2) = \frac{1}{2^{N/2}\Gamma(N/2)} \chi^{2[(N/2)-1]} e^{-(\chi^2)/2}$$ (Howell, 2002)

where N = degrees of freedom, and Γ(N/2) is the Gamma function, which was computed using the Excel function library.

For N=1, using values from 0.01 to 10 in increments of .01 as the argument, the Excel function library returns a Gamma function that looks like this:



Using the probability $f(\chi^2)$ given above, for $\chi^2 = 28$, $f(\chi^2) = 1.67 \times 10^{-8}$.

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