

**KNOT  
THEORY  
AND  
PHYSICS**

**DROR  
BAR-NATAN**



1  
00:00:04,710 --> 00:00:02,310  
drawer barnatan is a professor of pure

2  
00:00:06,869 --> 00:00:04,720  
mathematics at the university of toronto

3  
00:00:09,030 --> 00:00:06,879  
previously specializing in not theory

4  
00:00:11,430 --> 00:00:09,040  
and more recently specializing in finite

5  
00:00:13,030 --> 00:00:11,440  
type invariants and kavanaugh homology

6  
00:00:15,270 --> 00:00:13,040  
we touch on quantum field theory's

7  
00:00:17,510 --> 00:00:15,280  
connection to not theory how to learn

8  
00:00:19,990 --> 00:00:17,520  
mathematics in general we also touch on

9  
00:00:22,390 --> 00:00:20,000  
ed witton as jorah barnatan's advisor

10  
00:00:23,990 --> 00:00:22,400  
for his phd was edwitten and drawer

11  
00:00:26,790 --> 00:00:24,000  
gives some anecdotes about eric

12  
00:00:29,509 --> 00:00:26,800  
weinstein as while eric was pursuing his

13  
00:00:31,830 --> 00:00:29,519

phd drawer served as an informal advisor

14

00:00:33,750 --> 00:00:31,840

to eric at harvard professor barnatan

15

00:00:35,270 --> 00:00:33,760

taught a course in linear algebra that i

16

00:00:37,510 --> 00:00:35,280

took while i was at the university of

17

00:00:39,350 --> 00:00:37,520

toronto although i was a terrible

18

00:00:41,510 --> 00:00:39,360

student and i regret that i skipped the

19

00:00:43,910 --> 00:00:41,520

majority of his classes because he had

20

00:00:45,910 --> 00:00:43,920

an exceedingly intuitive approach for

21

00:00:47,990 --> 00:00:45,920

example there are vector space axioms

22

00:00:49,510 --> 00:00:48,000

can i i do and they seem extremely

23

00:00:51,110 --> 00:00:49,520

disconnected from any reason or

24

00:00:52,869 --> 00:00:51,120

motivation so what the professor would

25

00:00:54,549 --> 00:00:52,879

do would be before introducing a

26

00:00:56,709 --> 00:00:54,559

particular abstraction he would say

27

00:00:58,470 --> 00:00:56,719

imagine seven times a vector instead of

28

00:01:00,549 --> 00:00:58,480

imagine a times a vector and then

29

00:01:02,549 --> 00:01:00,559

generalize it which gave the abstraction

30

00:01:04,789 --> 00:01:02,559

some concreteness for those new to this

31

00:01:06,710 --> 00:01:04,799

channel my name is kurt jaimungal i'm a

32

00:01:09,109 --> 00:01:06,720

filmmaker with a background in math and

33

00:01:11,270 --> 00:01:09,119

physics dedicated to explicating what

34

00:01:13,190 --> 00:01:11,280

are called theories of everything from a

35

00:01:14,630 --> 00:01:13,200

mathematical physics perspective but

36

00:01:16,310 --> 00:01:14,640

also the possible connections

37

00:01:18,630 --> 00:01:16,320

consciousness has to the fundamental

38

00:01:20,550 --> 00:01:18,640

laws of nature provided these laws exist

39

00:01:22,630 --> 00:01:20,560

at all and are knowable to us this

40

00:01:24,310 --> 00:01:22,640

particular podcast isn't one to be

41

00:01:25,990 --> 00:01:24,320

listened to or at least you can but

42

00:01:27,590 --> 00:01:26,000

you're going to be frustrated as what's

43

00:01:29,429 --> 00:01:27,600

being referred to are one-dimensional

44

00:01:31,830 --> 00:01:29,439

objects embedded in a three-dimensional

45

00:01:33,510 --> 00:01:31,840

space in some configuration and the

46

00:01:35,590 --> 00:01:33,520

verbal description leaves much to be

47

00:01:37,830 --> 00:01:35,600

desired if you're listening to this on

48

00:01:39,270 --> 00:01:37,840

spotify or itunes i recommend you click

49

00:01:41,830 --> 00:01:39,280

the link in the description and follow

50

00:01:43,749 --> 00:01:41,840

along you can also download a pdf of the

51  
00:01:45,670 --> 00:01:43,759  
written notes from this podcast in the

52  
00:01:48,069 --> 00:01:45,680  
description as well there are a couple

53  
00:01:50,310 --> 00:01:48,079  
sponsors of today's podcast the first is

54  
00:01:52,469 --> 00:01:50,320  
also which is an end-to-end supply chain

55  
00:01:54,149 --> 00:01:52,479  
optimization software company with

56  
00:01:56,310 --> 00:01:54,159  
software that helps business users

57  
00:01:58,550 --> 00:01:56,320  
optimize sales and operations planning

58  
00:02:00,630 --> 00:01:58,560  
to avoid stockouts reduce returns and

59  
00:02:02,870 --> 00:02:00,640  
inventory write downs while reducing

60  
00:02:05,510 --> 00:02:02,880  
inventory investment it's a supply chain

61  
00:02:07,749 --> 00:02:05,520  
ai that drives smart roi headed by a

62  
00:02:09,109 --> 00:02:07,759  
bright individual named amjad hussein

63  
00:02:11,589 --> 00:02:09,119

who's been a huge supporter of the

64

00:02:13,270 --> 00:02:11,599

podcast from his early days the second

65

00:02:15,430 --> 00:02:13,280

sponsor is brilliant brilliant

66

00:02:17,110 --> 00:02:15,440

illuminates the soul of mathematics

67

00:02:18,630 --> 00:02:17,120

science and engineering through

68

00:02:20,869 --> 00:02:18,640

bite-sized interactive learning

69

00:02:22,790 --> 00:02:20,879

experiences brilliance courses explore

70

00:02:24,470 --> 00:02:22,800

the laws that shape our world elevating

71

00:02:26,390 --> 00:02:24,480

math and science from something to be

72

00:02:28,309 --> 00:02:26,400

feared to a delightful experience of

73

00:02:29,750 --> 00:02:28,319

guided discovery you can even learn

74

00:02:31,030 --> 00:02:29,760

group theory which is what's being

75

00:02:34,070 --> 00:02:31,040

referred to when you hear that the

76  
00:02:37,670 --> 00:02:34,080  
standard model is based on u1 cross su-2

77  
00:02:40,229 --> 00:02:37,680  
cross su-3 visit [brilliant.org](http://brilliant.org) slash toe

78  
00:02:41,990 --> 00:02:40,239  
that is t-o-e to get 20 off the annual

79  
00:02:44,150 --> 00:02:42,000  
subscription i recommend that you at

80  
00:02:45,830 --> 00:02:44,160  
least try the free trial and don't stop

81  
00:02:47,509 --> 00:02:45,840  
before four lessons and you'll be

82  
00:02:49,190 --> 00:02:47,519  
greatly surprised at the ease at which

83  
00:02:50,790 --> 00:02:49,200  
you can comprehend concepts that you

84  
00:02:52,390 --> 00:02:50,800  
previously had a difficult time

85  
00:02:54,550 --> 00:02:52,400  
understanding if you'd like to hear more

86  
00:02:57,350 --> 00:02:54,560  
conversations like this then do consider

87  
00:02:58,949 --> 00:02:57,360  
going to [patreon.com](http://patreon.com) kurtjimungle

88  
00:03:00,630 --> 00:02:58,959

there's also a crypto address and a

89

00:03:02,630 --> 00:03:00,640

paypal address if that's more up your

90

00:03:04,550 --> 00:03:02,640

alley i now do this full time and the

91

00:03:06,630 --> 00:03:04,560

patrons are what allow for me to put out

92

00:03:08,710 --> 00:03:06,640

this content on such a frequent basis

93

00:03:10,229 --> 00:03:08,720

every dollar helps certainly and

94

00:03:13,030 --> 00:03:10,239

regardless i'm grateful for your

95

00:03:15,550 --> 00:03:13,040

viewership again that's patreon.com

96

00:03:17,509 --> 00:03:15,560

kurtjungle

97

00:03:20,470 --> 00:03:17,519

c-u-r-t-j-a-i-m-u-n-g-a-l thank you and

98

00:03:25,750 --> 00:03:20,480

enjoy i actually had you as a professor

99

00:03:29,589 --> 00:03:28,070

i hope you didn't suffer too much

100

00:03:31,270 --> 00:03:29,599

that my favorite aspect of the course

101  
00:03:32,710 --> 00:03:31,280  
was that you would use the word seven

102  
00:03:35,750 --> 00:03:32,720  
you give an example of a number so you'd

103  
00:03:37,670 --> 00:03:35,760  
say a certain field number times a

104  
00:03:39,030 --> 00:03:37,680  
vector well let's call it seven so seven

105  
00:03:41,750 --> 00:03:39,040  
times a vector would be so-and-so you

106  
00:03:45,110 --> 00:03:41,760  
know it can get to extremes right you

107  
00:03:46,710 --> 00:03:45,120  
may end up doing things like uh

108  
00:03:51,270 --> 00:03:46,720  
the limit

109  
00:03:52,949 --> 00:03:51,280  
of uh  $e$  to the minus seven uh seven goes

110  
00:03:56,390 --> 00:03:52,959  
to infinity

111  
00:03:57,750 --> 00:03:56,400  
uh is equal to whatever it is zero right

112  
00:04:00,309 --> 00:03:57,760  
anyway yes

113  
00:04:02,949 --> 00:04:00,319

what's your field of research

114

00:04:04,309 --> 00:04:02,959

uh not theory

115

00:04:07,830 --> 00:04:04,319

and

116

00:04:09,350 --> 00:04:07,840

from a very algebraic perspective

117

00:04:11,270 --> 00:04:09,360

and

118

00:04:13,589 --> 00:04:11,280

related

119

00:04:15,270 --> 00:04:13,599

algebra things

120

00:04:16,069 --> 00:04:15,280

it used to be

121

00:04:18,469 --> 00:04:16,079

uh

122

00:04:22,710 --> 00:04:18,479

much more not theory and quantum field

123

00:04:25,110 --> 00:04:22,720

theory and it slowly slowly moved to to

124

00:04:27,110 --> 00:04:25,120

being much more algebraic and their

125

00:04:29,909 --> 00:04:27,120

relationship with quantum field theory

126

00:04:31,909 --> 00:04:29,919

became more and more remote

127

00:04:33,350 --> 00:04:31,919

okay what's the relationship let's

128

00:04:35,030 --> 00:04:33,360

forget about the remoteness what's the

129

00:04:38,710 --> 00:04:35,040

close relationship between not theory

130

00:04:43,749 --> 00:04:40,830

oh it's a bit hard to

131

00:04:46,950 --> 00:04:43,759

explain and somewhat surprising and

132

00:04:49,670 --> 00:04:46,960

that's why that's why it took a long

133

00:04:51,990 --> 00:04:49,680

time to discover

134

00:04:53,670 --> 00:04:52,000

let me give you

135

00:04:55,350 --> 00:04:53,680

two answers

136

00:04:59,110 --> 00:04:55,360

that are

137

00:05:01,270 --> 00:04:59,120

somewhat unrelated and

138

00:05:06,469 --> 00:05:01,280

one answer is that quantum field theory

139

00:05:11,430 --> 00:05:07,990

and

140

00:05:14,790 --> 00:05:11,440

note theory is surprisingly also about

141

00:05:15,749 --> 00:05:14,800

the motion of particles

142

00:05:18,790 --> 00:05:15,759

so

143

00:05:19,830 --> 00:05:18,800

uh you know let's draw a simple minded

144

00:05:20,950 --> 00:05:19,840

knot

145

00:05:23,510 --> 00:05:20,960

uh

146

00:05:26,710 --> 00:05:23,520

so by the way is this a visible

147

00:05:32,390 --> 00:05:26,720

skin yeah okay so here is a simple

148

00:05:38,790 --> 00:05:36,390

it's actually the so-called trefoil knot

149

00:05:40,469 --> 00:05:38,800

but uh

150

00:05:43,830 --> 00:05:40,479

well whatever it is

151

00:05:45,189 --> 00:05:43,840

uh now uh what you can do

152

00:05:49,189 --> 00:05:45,199

is you can

153

00:05:53,909 --> 00:05:49,199

uh so it's living in in  $r^3$

154

00:05:55,350 --> 00:05:53,919

and uh i could set up my coordinates

155

00:05:56,150 --> 00:05:55,360

so that

156

00:05:58,790 --> 00:05:56,160

uh

157

00:06:00,710 --> 00:05:58,800

this coordinate will be called  $t$  maybe

158

00:06:03,670 --> 00:06:00,720

you want to call it  $z$

159

00:06:06,950 --> 00:06:03,680

but you know i like to call it  $t$  at uh

160

00:06:09,830 --> 00:06:06,960

right now and the two coordinates here

161

00:06:14,629 --> 00:06:09,840

are  $x$  and  $y$

162

00:06:15,430 --> 00:06:14,639

and then i can slice this knot

163

00:06:18,150 --> 00:06:15,440

at

164

00:06:22,550 --> 00:06:18,160

uh equal time

165

00:06:24,790 --> 00:06:22,560

uh slices so basically i uh

166

00:06:28,710 --> 00:06:24,800

draw a plane

167

00:06:32,309 --> 00:06:28,720

which leaves at some fixed height

168

00:06:36,790 --> 00:06:32,319

so at an equal in an equal time plane

169

00:06:39,670 --> 00:06:36,800

and slice the knot and then the slice is

170

00:06:43,510 --> 00:06:39,680

four points

171

00:06:45,510 --> 00:06:43,520

and as i move these points

172

00:06:50,150 --> 00:06:45,520

in time

173

00:06:52,390 --> 00:06:50,160

points move

174

00:06:54,070 --> 00:06:52,400

and they actually do a little lovely

175

00:06:54,950 --> 00:06:54,080

dance

176  
00:06:57,749 --> 00:06:54,960  
and

177  
00:06:59,909 --> 00:06:57,759  
uh the dance is as follows so if we call

178  
00:07:00,790 --> 00:06:59,919  
these points uh

179  
00:07:01,510 --> 00:07:00,800  
a

180  
00:07:03,189 --> 00:07:01,520  
b

181  
00:07:07,350 --> 00:07:03,199  
c and d

182  
00:07:08,870 --> 00:07:07,360  
then they start at a certain position

183  
00:07:11,430 --> 00:07:08,880  
a b

184  
00:07:12,309 --> 00:07:11,440  
c and d

185  
00:07:13,270 --> 00:07:12,319  
right

186  
00:07:15,909 --> 00:07:13,280  
and then

187  
00:07:17,029 --> 00:07:15,919  
as i move

188  
00:07:19,589 --> 00:07:17,039

uh

189

00:07:22,870 --> 00:07:19,599

well you can see that c and b trade

190

00:07:24,870 --> 00:07:22,880

places so they play a dance they somehow

191

00:07:26,230 --> 00:07:24,880

dance around each other

192

00:07:31,510 --> 00:07:26,240

uh

193

00:07:37,510 --> 00:07:31,520

goes

194

00:07:38,870 --> 00:07:37,520

after a little while they trade places

195

00:07:40,790 --> 00:07:38,880

so you have

196

00:07:42,070 --> 00:07:40,800

a c

197

00:07:43,189 --> 00:07:42,080

sorry a

198

00:07:44,710 --> 00:07:43,199

uh

199

00:07:45,510 --> 00:07:44,720

c b

200

00:07:51,270 --> 00:07:45,520

d

201  
00:07:55,510 --> 00:07:51,280  
so

202  
00:07:59,110 --> 00:07:55,520  
uh again you will have a a b

203  
00:08:02,629 --> 00:07:59,120  
a c d and if you move a little further

204  
00:08:04,710 --> 00:08:02,639  
again they trade places so you'll have a

205  
00:08:07,990 --> 00:08:04,720  
c b d

206  
00:08:09,110 --> 00:08:08,000  
and then something funny happens

207  
00:08:11,350 --> 00:08:09,120  
uh

208  
00:08:12,390 --> 00:08:11,360  
points

209  
00:08:15,270 --> 00:08:12,400  
uh

210  
00:08:18,390 --> 00:08:15,280  
well points well by this time this is

211  
00:08:19,430 --> 00:08:18,400  
point b is over here and point c is over

212  
00:08:25,350 --> 00:08:19,440  
here

213  
00:08:27,990 --> 00:08:25,360

what happens is that point c moves

214

00:08:30,790 --> 00:08:28,000

towards point d

215

00:08:31,510 --> 00:08:30,800

and points a more moves to points point

216

00:08:34,870 --> 00:08:31,520

b

217

00:08:35,909 --> 00:08:34,880

and they coincide

218

00:08:38,310 --> 00:08:35,919

and

219

00:08:40,230 --> 00:08:38,320

when they coincide they annihilate each

220

00:08:42,310 --> 00:08:40,240

other because if you look at the plane

221

00:08:43,269 --> 00:08:42,320

which is above

222

00:08:48,150 --> 00:08:43,279

the

223

00:08:51,190 --> 00:08:49,190

uh

224

00:08:53,350 --> 00:08:51,200

you no longer see any point so what

225

00:08:55,350 --> 00:08:53,360

happens next is that these points move

226

00:08:57,990 --> 00:08:55,360

towards each other these points move to

227

00:09:00,470 --> 00:08:58,000

each other they meet and bang they

228

00:09:02,630 --> 00:09:00,480

annihilate and after that there is an

229

00:09:06,150 --> 00:09:02,640

empty set

230

00:09:08,710 --> 00:09:06,160

and in fact i started a tight

231

00:09:12,310 --> 00:09:08,720

uh at a certain height had i started

232

00:09:15,509 --> 00:09:12,320

below i start with the empty set

233

00:09:18,230 --> 00:09:15,519

and instead of annihilation of pairs

234

00:09:20,070 --> 00:09:18,240

you get a creation of pairs so a pair of

235

00:09:22,630 --> 00:09:20,080

points get created here and a pair of

236

00:09:24,949 --> 00:09:22,640

points get created here and then they

237

00:09:27,350 --> 00:09:24,959

perform this nice dance

238

00:09:30,070 --> 00:09:27,360

so this was this particular note but the

239

00:09:33,030 --> 00:09:30,080

same story is true for every note every

240

00:09:35,110 --> 00:09:33,040

note can be written as a certain dance

241

00:09:39,590 --> 00:09:35,120

of points

242

00:09:42,710 --> 00:09:39,600

in which uh sometimes pairs

243

00:09:45,110 --> 00:09:42,720

get created sometimes pair meet and

244

00:09:48,829 --> 00:09:45,120

annihilate each other and in between

245

00:09:51,110 --> 00:09:48,839

these times they all dance

246

00:09:53,670 --> 00:09:51,120

anyway uh

247

00:09:57,269 --> 00:09:53,680

physics in general is about the motion

248

00:09:59,829 --> 00:09:57,279

of particles and it's not too surprising

249

00:10:02,949 --> 00:09:59,839

that there is a relationship

250

00:10:05,829 --> 00:10:02,959

physics also sees things like creation

251  
00:10:08,389 --> 00:10:05,839  
and annihilation of pairs of particles

252  
00:10:09,829 --> 00:10:08,399  
and i mean so again it's not so

253  
00:10:13,509 --> 00:10:09,839  
surprising

254  
00:10:15,910 --> 00:10:13,519  
but this is very very very loose

255  
00:10:21,190 --> 00:10:18,310  
gee the other explanation i can give you

256  
00:10:22,230 --> 00:10:21,200  
is even more loose

257  
00:10:24,870 --> 00:10:22,240  
uh

258  
00:10:26,389 --> 00:10:24,880  
but even but but in some sense

259  
00:10:27,590 --> 00:10:26,399  
more

260  
00:10:31,350 --> 00:10:27,600  
um

261  
00:10:37,509 --> 00:10:34,630  
uh well okay maybe you've heard

262  
00:10:39,910 --> 00:10:37,519  
that quantum mechanics is related to

263  
00:10:40,710 --> 00:10:39,920

path integrals

264

00:10:43,990 --> 00:10:40,720

so

265

00:10:44,949 --> 00:10:44,000

uh you know in classical mechanics

266

00:10:47,910 --> 00:10:44,959

uh

267

00:10:49,269 --> 00:10:47,920

you know if a path goes from point a to

268

00:10:51,750 --> 00:10:49,279

point b

269

00:10:52,870 --> 00:10:51,760

sorry if a particle goes from point a to

270

00:10:57,030 --> 00:10:52,880

point b

271

00:10:58,310 --> 00:10:57,040

it goes along a specific path

272

00:11:03,829 --> 00:10:58,320

um

273

00:11:06,150 --> 00:11:03,839

probability of going uh from a to b and

274

00:11:08,069 --> 00:11:06,160

you compute this probability

275

00:11:09,750 --> 00:11:08,079

by doing a certain

276  
00:11:13,509 --> 00:11:09,760  
integral

277  
00:11:16,310 --> 00:11:13,519  
over the space of all paths

278  
00:11:19,110 --> 00:11:16,320  
so the particle or

279  
00:11:21,110 --> 00:11:19,120  
i mean again even even my interpretation

280  
00:11:22,790 --> 00:11:21,120  
of quantum mechanics here is a bit loose

281  
00:11:24,949 --> 00:11:22,800  
because interpreting quantum mechanics

282  
00:11:28,870 --> 00:11:24,959  
is a very hard thing

283  
00:11:31,430 --> 00:11:28,880  
but with this loose interpretation you

284  
00:11:35,110 --> 00:11:31,440  
sum over all probabilities of going this

285  
00:11:38,150 --> 00:11:35,120  
way or that way or that way

286  
00:11:40,829 --> 00:11:38,160  
or that way and by adding up all these

287  
00:11:43,670 --> 00:11:40,839  
probabilities or more precisely

288  
00:11:46,069 --> 00:11:43,680

integrating over the space of all of

289

00:11:48,470 --> 00:11:46,079

those probabilities or more precisely

290

00:11:51,190 --> 00:11:48,480

phase factors or

291

00:11:52,629 --> 00:11:51,200

amplitudes

292

00:11:55,030 --> 00:11:52,639

uh you

293

00:11:58,870 --> 00:11:55,040

you can compute the probability of going

294

00:11:59,990 --> 00:11:58,880

from a to b that's quantum mechanics

295

00:12:01,750 --> 00:12:00,000

now

296

00:12:06,230 --> 00:12:01,760

uh

297

00:12:07,910 --> 00:12:06,240

quantum field theory it's essentially

298

00:12:10,470 --> 00:12:07,920

the same except the integrals are more

299

00:12:13,829 --> 00:12:10,480

complicated but the point is that

300

00:12:18,389 --> 00:12:13,839

already these integrals

301  
00:12:20,150 --> 00:12:18,399  
are not like integrals over  $\mathbb{R}^n$

302  
00:12:24,629 --> 00:12:20,160  
right  $\mathbb{R}^n$

303  
00:12:28,389 --> 00:12:24,639  
is uh the collection of  $n$  tuples of

304  
00:12:32,629 --> 00:12:28,399  
points  $a_1$  up to  $a_n$

305  
00:12:34,949 --> 00:12:32,639  
so a point in  $\mathbb{R}^n$  is determined by  $n$

306  
00:12:37,750 --> 00:12:34,959  
real numbers

307  
00:12:40,470 --> 00:12:37,760  
whereas a function the space we are

308  
00:12:42,710 --> 00:12:40,480  
integrating over now

309  
00:12:43,829 --> 00:12:42,720  
is the space of all functions and a

310  
00:12:46,710 --> 00:12:43,839  
function

311  
00:12:49,190 --> 00:12:46,720  
is determined by infinitely many real

312  
00:12:50,949 --> 00:12:49,200  
values you need to know the value of the

313  
00:12:52,470 --> 00:12:50,959

function here the value of the function

314

00:12:54,389 --> 00:12:52,480

here the value of the function here the

315

00:12:56,470 --> 00:12:54,399

value of the function here so to

316

00:12:58,870 --> 00:12:56,480

determine a function you need to know

317

00:13:01,509 --> 00:12:58,880

infinite infinitely many

318

00:13:06,550 --> 00:13:01,519

uh real numbers

319

00:13:07,310 --> 00:13:06,560

so the integral that you end up doing is

320

00:13:11,350 --> 00:13:07,320

not

321

00:13:13,750 --> 00:13:11,360

157 style sorry now i'm using a

322

00:13:17,269 --> 00:13:13,760

toronto style language or it's not one

323

00:13:20,230 --> 00:13:17,279

variable calculus in integral which is

324

00:13:23,509 --> 00:13:20,240

again one variable

325

00:13:26,069 --> 00:13:23,519

uh integral it's not this

326

00:13:28,069 --> 00:13:26,079

it's not second year calculus when you

327

00:13:30,310 --> 00:13:28,079

do n variable

328

00:13:33,990 --> 00:13:30,320

uh integrals

329

00:13:37,350 --> 00:13:34,000

it's infinite dimensional so infinitely

330

00:13:39,189 --> 00:13:37,360

many variables integration this is what

331

00:13:40,629 --> 00:13:39,199

we need

332

00:13:41,829 --> 00:13:40,639

okay

333

00:13:42,790 --> 00:13:41,839

so

334

00:13:47,829 --> 00:13:42,800

uh

335

00:13:53,430 --> 00:13:50,310

ended up developing

336

00:13:56,790 --> 00:13:53,440

a bag of techniques for computing

337

00:13:58,870 --> 00:13:56,800

infinite dimensional integrals

338

00:14:00,389 --> 00:13:58,880

and what these techniques are is a whole

339

00:14:03,829 --> 00:14:00,399

different story

340

00:14:05,910 --> 00:14:03,839

but uh but quantum field theory ended up

341

00:14:07,030 --> 00:14:05,920

doing this

342

00:14:08,470 --> 00:14:07,040

and then

343

00:14:10,389 --> 00:14:08,480

uh

344

00:14:13,189 --> 00:14:10,399

it turns out

345

00:14:15,590 --> 00:14:13,199

that infinite dimensional integrals are

346

00:14:17,910 --> 00:14:15,600

useful to topology

347

00:14:20,069 --> 00:14:17,920

so so the the the

348

00:14:22,629 --> 00:14:20,079

the way that quantum field theory

349

00:14:25,030 --> 00:14:22,639

becomes useful in topology is indirect

350

00:14:26,710 --> 00:14:25,040

it's not that the quantum field theory

351  
00:14:28,870 --> 00:14:26,720  
itself

352  
00:14:30,949 --> 00:14:28,880  
is useful

353  
00:14:33,110 --> 00:14:30,959  
even this is a lie because sometimes the

354  
00:14:35,509 --> 00:14:33,120  
quantum field theory itself is useful

355  
00:14:38,230 --> 00:14:35,519  
but but the main path by which quantum

356  
00:14:39,430 --> 00:14:38,240  
filter becomes useful to topology

357  
00:14:40,389 --> 00:14:39,440  
is not

358  
00:14:45,670 --> 00:14:40,399  
uh

359  
00:14:48,310 --> 00:14:45,680  
field theory developed a bag of

360  
00:14:51,829 --> 00:14:48,320  
techniques and this bag of techniques

361  
00:14:55,990 --> 00:14:54,550  
anyway why are infinite dimensional

362  
00:14:58,790 --> 00:14:56,000  
integrals

363  
00:15:00,069 --> 00:14:58,800

useful to topology

364

00:15:03,430 --> 00:15:00,079

um

365

00:15:04,949 --> 00:15:03,440

the answer is again a bit

366

00:15:06,389 --> 00:15:04,959

uh

367

00:15:08,949 --> 00:15:06,399

complicated

368

00:15:13,110 --> 00:15:08,959

but let me try to summarize it

369

00:15:15,110 --> 00:15:13,120

so let me bring a knot here's a knot

370

00:15:16,310 --> 00:15:15,120

okay great

371

00:15:21,590 --> 00:15:16,320

uh

372

00:15:25,350 --> 00:15:21,600

why not picking what i'm showing you is

373

00:15:28,150 --> 00:15:27,110

a note

374

00:15:30,470 --> 00:15:28,160

is

375

00:15:38,150 --> 00:15:35,269

an equivalence class of such curves so

376

00:15:40,470 --> 00:15:38,160

this is a curve if i deform it a bit

377

00:15:43,509 --> 00:15:40,480

it's still a curve but it's considered

378

00:15:45,749 --> 00:15:43,519

the same knot if i deform it some more

379

00:15:47,829 --> 00:15:45,759

it's still a curve but it con but but

380

00:15:50,310 --> 00:15:47,839

but but it's the same not

381

00:15:53,590 --> 00:15:50,320

so a knot is not a single curve but an

382

00:15:56,069 --> 00:15:53,600

equivalent class of curves

383

00:15:59,749 --> 00:15:56,079

now suppose you want

384

00:16:03,110 --> 00:15:59,759

quantities that are associated to notes

385

00:16:04,470 --> 00:16:03,120

you want to be able to tell notes apart

386

00:16:05,910 --> 00:16:04,480

so you need

387

00:16:08,470 --> 00:16:05,920

quantities

388

00:16:10,550 --> 00:16:08,480

uh that would be computable from the

389

00:16:12,150 --> 00:16:10,560

knot and that you would use them to tell

390

00:16:14,150 --> 00:16:12,160

the notes apart

391

00:16:17,389 --> 00:16:14,160

okay

392

00:16:19,030 --> 00:16:17,399

now it's very easy to compute

393

00:16:22,629 --> 00:16:19,040

quantities

394

00:16:25,189 --> 00:16:22,639

that are associated with curves

395

00:16:29,110 --> 00:16:25,199

so if you have a curve

396

00:16:32,790 --> 00:16:29,120

uh you can measure its how much it bends

397

00:16:35,509 --> 00:16:32,800

so the radius of of the bending

398

00:16:38,230 --> 00:16:35,519

okay again these things have technical

399

00:16:39,509 --> 00:16:38,240

names the curvature maybe the torsion

400

00:16:42,150 --> 00:16:39,519

there are various

401  
00:16:43,590 --> 00:16:42,160  
names for for various quantities you can

402  
00:16:44,870 --> 00:16:43,600  
associate with

403  
00:16:47,430 --> 00:16:44,880  
curves

404  
00:16:51,030 --> 00:16:47,440  
so you know i can look at the maximal

405  
00:16:53,030 --> 00:16:51,040  
curvature of this knot of this curve and

406  
00:16:55,269 --> 00:16:53,040  
the maximal curvature will be the place

407  
00:16:57,910 --> 00:16:55,279  
where it turns the most and that's

408  
00:17:00,710 --> 00:16:57,920  
probably around here for this particular

409  
00:17:03,269 --> 00:17:00,720  
curve around here okay

410  
00:17:06,630 --> 00:17:03,279  
now um

411  
00:17:09,590 --> 00:17:06,640  
uh but that quantity is a quantity which

412  
00:17:12,630 --> 00:17:09,600  
is associated with curves

413  
00:17:14,710 --> 00:17:12,640

it's a useless as a quantity for not

414

00:17:16,710 --> 00:17:14,720

it's useless as a quantity for knots

415

00:17:19,350 --> 00:17:16,720

because if we're talking about not you

416

00:17:22,470 --> 00:17:19,360

know i could deform it and the maximal

417

00:17:25,590 --> 00:17:22,480

curvature could go somewhere else

418

00:17:26,789 --> 00:17:25,600

could change could grow could shrink

419

00:17:27,990 --> 00:17:26,799

could differ

420

00:17:31,430 --> 00:17:28,000

right

421

00:17:32,789 --> 00:17:31,440

so the way to get quantities that are

422

00:17:34,630 --> 00:17:32,799

associated

423

00:17:36,230 --> 00:17:34,640

with knots

424

00:17:37,590 --> 00:17:36,240

rather than with

425

00:17:41,669 --> 00:17:37,600

curves

426

00:17:44,310 --> 00:17:41,679

is to integrate over the space of all

427

00:17:47,270 --> 00:17:44,320

geometries

428

00:17:50,470 --> 00:17:47,280

so instead of picking the quantity for a

429

00:17:51,990 --> 00:17:50,480

specific geometric manifestation of the

430

00:17:54,390 --> 00:17:52,000

knot

431

00:17:57,909 --> 00:17:54,400

you integrate over the space of all

432

00:18:00,750 --> 00:17:57,919

geometries and then the result will be a

433

00:18:03,510 --> 00:18:00,760

a quantity associated with the note

434

00:18:04,789 --> 00:18:03,520

unfortunately the examples are very very

435

00:18:07,990 --> 00:18:04,799

hard

436

00:18:10,230 --> 00:18:08,000

so you know the the famous example the

437

00:18:13,430 --> 00:18:10,240

example that uh

438

00:18:15,510 --> 00:18:13,440

got written uh well one of the examples

439

00:18:18,789 --> 00:18:15,520

that got written very very famous in

440

00:18:22,390 --> 00:18:18,799

topology or among mathematicians is the

441

00:18:26,950 --> 00:18:22,400

so-called chern simon's theory

442

00:18:31,590 --> 00:18:26,960

uh or chen simon's quantity which is um

443

00:18:35,430 --> 00:18:31,600

uh so uh in itself some integral so you

444

00:18:38,470 --> 00:18:35,440

integrate over  $\mathbb{R}^3$

445

00:18:40,710 --> 00:18:38,480

so the quantity itself is a finite

446

00:18:45,110 --> 00:18:40,720

dimensional integral

447

00:18:48,070 --> 00:18:45,120

right so you integrate over  $\mathbb{R}^3$  something

448

00:18:50,789 --> 00:18:48,080

called the chern simon's form

449

00:18:52,470 --> 00:18:50,799

uh which is something called which is a

450

00:18:54,630 --> 00:18:52,480

wedge  $d a$

451  
00:18:55,590 --> 00:18:54,640  
plus two thirds

452  
00:18:58,470 --> 00:18:55,600  
uh

453  
00:19:00,710 --> 00:18:58,480  
a wedge a wedge a

454  
00:19:03,029 --> 00:19:00,720  
whatever that is but this is you know

455  
00:19:05,750 --> 00:19:03,039  
related to stuff appearing in second

456  
00:19:08,710 --> 00:19:05,760  
year uh multivariable calculus in the

457  
00:19:10,630 --> 00:19:08,720  
most advanced versions okay so wedge

458  
00:19:13,669 --> 00:19:10,640  
products and differential forms and

459  
00:19:16,950 --> 00:19:13,679  
exterior derivatives and stuff like that

460  
00:19:20,190 --> 00:19:16,960  
then you take this quantity and you

461  
00:19:22,230 --> 00:19:20,200  
multiply it by i multiply by k

462  
00:19:25,510 --> 00:19:22,240  
exponentiate it

463  
00:19:29,510 --> 00:19:25,520

multiply by another quantity the

464

00:19:32,150 --> 00:19:29,520

so-called holonomy along the note of a

465

00:19:34,390 --> 00:19:32,160

whatever that is so i'm throwing names

466

00:19:36,070 --> 00:19:34,400

because i really have no choice because

467

00:19:38,710 --> 00:19:36,080

giving the precise definition is a

468

00:19:41,430 --> 00:19:38,720

matter for a graduate class yeah okay

469

00:19:45,909 --> 00:19:41,440

and this is the quantity that you

470

00:19:49,270 --> 00:19:45,919

associate with a geometric note

471

00:19:51,830 --> 00:19:49,280

and then to get an invariant of notes or

472

00:19:53,510 --> 00:19:51,840

to get a quantity associated with the

473

00:19:55,990 --> 00:19:53,520

not itself

474

00:19:59,270 --> 00:19:56,000

you integrate it

475

00:20:01,350 --> 00:19:59,280

over the space of all such a's and i

476  
00:20:03,110 --> 00:20:01,360  
didn't really tell you what these a's

477  
00:20:04,549 --> 00:20:03,120  
are but it's an infinite dimensional

478  
00:20:05,350 --> 00:20:04,559  
space

479  
00:20:08,149 --> 00:20:05,360  
so

480  
00:20:10,710 --> 00:20:08,159  
uh i guess i haven't really answered

481  
00:20:13,909 --> 00:20:10,720  
your question by giving an example but i

482  
00:20:16,549 --> 00:20:13,919  
just told you the examples are hard

483  
00:20:19,110 --> 00:20:16,559  
okay anyway um

484  
00:20:20,630 --> 00:20:19,120  
well they're hard but they're exactly of

485  
00:20:21,430 --> 00:20:20,640  
the nature

486  
00:20:24,149 --> 00:20:21,440  
that

487  
00:20:26,710 --> 00:20:24,159  
physics knows how to study

488  
00:20:27,909 --> 00:20:26,720

or that quantum field theory developed

489

00:20:31,510 --> 00:20:27,919

techniques

490

00:20:34,149 --> 00:20:31,520

to study and so one can study it using

491

00:20:37,590 --> 00:20:34,159

quantum field theory techniques and get

492

00:20:39,750 --> 00:20:37,600

all sorts of um

493

00:20:42,310 --> 00:20:39,760

well

494

00:20:45,270 --> 00:20:42,320

quantities relevance to not relevant to

495

00:20:46,950 --> 00:20:45,280

not the so-called jones polynomial is an

496

00:20:48,710 --> 00:20:46,960

example and then there are many other

497

00:20:50,950 --> 00:20:48,720

examples

498

00:20:53,510 --> 00:20:50,960

are there any relationships between not

499

00:20:55,029 --> 00:20:53,520

theory and gravity so general relativity

500

00:20:56,789 --> 00:20:55,039

let's say

501  
00:21:00,870 --> 00:20:56,799  
um

502  
00:21:05,350 --> 00:21:02,549  
i'm not an expert

503  
00:21:06,390 --> 00:21:05,360  
the answer is yes

504  
00:21:11,830 --> 00:21:06,400  
uh

505  
00:21:13,590 --> 00:21:11,840  
i told you i've actually moved away from

506  
00:21:15,190 --> 00:21:13,600  
that subject

507  
00:21:17,270 --> 00:21:15,200  
what got you interested in not theory

508  
00:21:19,110 --> 00:21:17,280  
originally

509  
00:21:21,110 --> 00:21:19,120  
this subject

510  
00:21:24,710 --> 00:21:21,120  
so mainly you were interested in physics

511  
00:21:25,590 --> 00:21:24,720  
well okay i was a math undergrad

512  
00:21:28,390 --> 00:21:25,600  
uh

513  
00:21:33,270 --> 00:21:31,590

during my time as an undergrad and then

514

00:21:36,230 --> 00:21:33,280

a master's student in tel aviv

515

00:21:39,029 --> 00:21:36,240

university i never finished the masters

516

00:21:41,430 --> 00:21:39,039

i moved on to doing my phd in in

517

00:21:43,830 --> 00:21:41,440

princeton but during my time as a

518

00:21:46,070 --> 00:21:43,840

master's student in in

519

00:21:49,029 --> 00:21:46,080

in tel aviv i got more and more

520

00:21:49,909 --> 00:21:49,039

interested in in physics

521

00:21:52,390 --> 00:21:49,919

and

522

00:21:54,390 --> 00:21:52,400

uh there's just wonderful mathematics

523

00:21:56,310 --> 00:21:54,400

inside physics so i got interested in

524

00:21:57,669 --> 00:21:56,320

physics and the fundamental question of

525

00:21:59,990 --> 00:21:57,679

physics right

526

00:22:03,350 --> 00:22:00,000

what are the basic laws of the universe

527

00:22:05,590 --> 00:22:03,360

i mean you can't ask a better question

528

00:22:07,669 --> 00:22:05,600

so i got more and more interested in

529

00:22:10,310 --> 00:22:07,679

physics and decided to do my phd in

530

00:22:13,430 --> 00:22:10,320

mathematical physics

531

00:22:18,070 --> 00:22:13,440

and i ended up uh working with ed

532

00:22:20,230 --> 00:22:18,080

wheaton uh who who is a very famous

533

00:22:23,990 --> 00:22:20,240

physicist or mathematical physicist or

534

00:22:27,270 --> 00:22:24,000

mathematician depending whom you ask

535

00:22:30,950 --> 00:22:27,280

and um

536

00:22:32,310 --> 00:22:30,960

uh and originally my interest was in

537

00:22:33,590 --> 00:22:32,320

physics

538

00:22:36,070 --> 00:22:33,600

or you know

539

00:22:37,990 --> 00:22:36,080

my aim was to do things that was rather

540

00:22:40,070 --> 00:22:38,000

were relevant to physics

541

00:22:41,750 --> 00:22:40,080

somehow that's not what happened you

542

00:22:42,789 --> 00:22:41,760

know at the end you don't choose your

543

00:22:47,990 --> 00:22:42,799

career

544

00:22:48,789 --> 00:22:48,000

you know so uh

545

00:23:09,430 --> 00:22:48,799

i

546

00:23:12,549 --> 00:23:09,440

turned out that that was relevant to

547

00:23:14,870 --> 00:23:12,559

something called finite type invariants

548

00:23:16,950 --> 00:23:14,880

and i thought i had new things to say

549

00:23:20,070 --> 00:23:16,960

about finite typing variance and that's

550

00:23:20,830 --> 00:23:20,080

completely and not theoretic subject

551  
00:23:22,070 --> 00:23:20,840  
so

552  
00:23:22,950 --> 00:23:22,080  
i uh

553  
00:23:34,870 --> 00:23:22,960  
i

554  
00:23:38,070 --> 00:23:34,880  
about and that paper or two became 10

555  
00:23:39,750 --> 00:23:38,080  
years with several paper many papers and

556  
00:23:41,430 --> 00:23:39,760  
many results and

557  
00:23:43,350 --> 00:23:41,440  
and

558  
00:23:45,430 --> 00:23:43,360  
you know

559  
00:23:47,510 --> 00:23:45,440  
and then a chinese meeting led me to yet

560  
00:23:49,830 --> 00:23:47,520  
another subject and you know

561  
00:23:51,269 --> 00:23:49,840  
what was the other subject it led you to

562  
00:23:53,590 --> 00:23:51,279  
um

563  
00:23:56,390 --> 00:23:53,600

well no the next subject after finite

564

00:23:58,549 --> 00:23:56,400

typing variance was juvano homology

565

00:24:02,549 --> 00:23:58,559

anyway you don't choose what you do you

566

00:24:03,669 --> 00:24:02,559

you know you you at most uh try to steer

567

00:24:04,470 --> 00:24:03,679

it

568

00:24:06,870 --> 00:24:04,480

but

569

00:24:07,990 --> 00:24:06,880

it steers you much more than you steer

570

00:24:09,909 --> 00:24:08,000

it

571

00:24:12,870 --> 00:24:09,919

like the subject do you have an

572

00:24:13,990 --> 00:24:12,880

intuitive explanation for people who

573

00:24:17,190 --> 00:24:14,000

let's say they're at the second year

574

00:24:23,350 --> 00:24:17,200

level what is a homology

575

00:24:27,750 --> 00:24:24,630

it's a tough

576

00:24:29,990 --> 00:24:27,760

a very tough uh

577

00:24:32,070 --> 00:24:30,000

question

578

00:24:35,350 --> 00:24:32,080

because

579

00:24:36,470 --> 00:24:35,360

it's many things or it's related to many

580

00:24:40,470 --> 00:24:36,480

things

581

00:24:41,830 --> 00:24:40,480

and i could answer it in in many levels

582

00:24:44,310 --> 00:24:41,840

um

583

00:24:46,630 --> 00:24:44,320

you know

584

00:24:49,430 --> 00:24:46,640

uh let me

585

00:24:50,549 --> 00:24:49,440

let me give you a summary answer

586

00:24:51,830 --> 00:24:50,559

sure okay

587

00:24:55,669 --> 00:24:51,840

so

588

00:25:05,029 --> 00:25:00,630

there are two ways to describe objects

589

00:25:09,990 --> 00:25:05,039

you can describe them implicitly

590

00:25:10,990 --> 00:25:10,000

by telling what equations they satisfy

591

00:25:12,710 --> 00:25:11,000

or

592

00:25:15,750 --> 00:25:12,720

explicitly

593

00:25:18,230 --> 00:25:15,760

by constructing all of them

594

00:25:19,110 --> 00:25:18,240

let me give you the simplest example

595

00:25:20,950 --> 00:25:19,120

so

596

00:25:22,950 --> 00:25:20,960

uh consider

597

00:25:25,830 --> 00:25:22,960

the unit circle

598

00:25:28,549 --> 00:25:25,840

sorry i kind of care about the points of

599

00:25:32,230 --> 00:25:28,559

the unit circle so here is the unit

600

00:25:34,870 --> 00:25:32,240

circle in the x y plane and here is a

601  
00:25:38,470 --> 00:25:34,880

point x y

602  
00:25:40,630 --> 00:25:38,480

the implicit description of the circle

603  
00:25:41,430 --> 00:25:40,640

so the implicit

604  
00:25:44,630 --> 00:25:41,440

is

605  
00:25:46,710 --> 00:25:44,640

by writing an equation which the points

606  
00:25:49,510 --> 00:25:46,720

have to satisfy and everybody knows what

607  
00:25:53,269 --> 00:25:49,520

the equation is the equation is x

608  
00:25:56,390 --> 00:25:53,279

squared minus sorry plus y squared minus

609  
00:25:57,830 --> 00:25:56,400

1 is equal to 0.

610  
00:25:58,710 --> 00:25:57,840

okay

611  
00:26:00,870 --> 00:25:58,720

uh

612  
00:26:02,630 --> 00:26:00,880

but there is also an explicit

613  
00:26:05,590 --> 00:26:02,640

description

614

00:26:07,990 --> 00:26:05,600

and again i'm not sure which one is

615

00:26:11,430 --> 00:26:08,000

why the naming is such but it it doesn't

616

00:26:14,630 --> 00:26:11,440

really matter namely i can construct all

617

00:26:17,669 --> 00:26:14,640

the points of the paper of the circle

618

00:26:18,870 --> 00:26:17,679

and the construction is you set  $x$  is

619

00:26:25,909 --> 00:26:18,880

equal to

620

00:26:31,350 --> 00:26:27,110

okay

621

00:26:34,070 --> 00:26:31,360

now this is the general

622

00:26:36,549 --> 00:26:34,080

a general feature in mathematics that

623

00:26:39,269 --> 00:26:36,559

many things can be described either be

624

00:26:42,789 --> 00:26:39,279

constructed that's the explicit

625

00:26:43,669 --> 00:26:42,799

or be defined by an equation

626  
00:26:45,830 --> 00:26:43,679  
now

627  
00:26:48,230 --> 00:26:45,840  
if you uh

628  
00:26:50,310 --> 00:26:48,240  
restrict your attention to linear

629  
00:26:53,669 --> 00:26:50,320  
algebra

630  
00:26:55,990 --> 00:26:53,679  
if you you you do the same thing but in

631  
00:26:56,950 --> 00:26:56,000  
linear algebra

632  
00:26:57,750 --> 00:26:56,960  
then

633  
00:26:59,909 --> 00:26:57,760  
uh

634  
00:27:01,990 --> 00:26:59,919  
the situation is that you have some

635  
00:27:02,950 --> 00:27:02,000  
space in the middle maybe it's a vector

636  
00:27:09,029 --> 00:27:02,960  
space

637  
00:27:10,870 --> 00:27:09,039  
describe things

638  
00:27:13,269 --> 00:27:10,880

actually i'm not sure why i'm drawing it

639

00:27:15,029 --> 00:27:13,279

curve because the curve because if it's

640

00:27:17,909 --> 00:27:15,039

linear algebra i should be drawing it

641

00:27:19,430 --> 00:27:17,919

straight but anyway you want to describe

642

00:27:23,029 --> 00:27:19,440

things

643

00:27:24,549 --> 00:27:23,039

and there are two ways to describe them

644

00:27:26,549 --> 00:27:24,559

one way

645

00:27:28,230 --> 00:27:26,559

is by saying

646

00:27:30,630 --> 00:27:28,240

these things

647

00:27:32,470 --> 00:27:30,640

well you construct a map into another

648

00:27:37,029 --> 00:27:32,480

space

649

00:27:39,190 --> 00:27:37,039

and you say these things are the things

650

00:27:41,830 --> 00:27:39,200

in the kernel

651  
00:27:43,269 --> 00:27:41,840  
of this map so i don't know what let's

652  
00:27:44,710 --> 00:27:43,279  
call this map

653  
00:27:46,630 --> 00:27:44,720  
fi

654  
00:27:51,430 --> 00:27:46,640  
and these things

655  
00:27:57,029 --> 00:27:52,549  
and then

656  
00:28:03,750 --> 00:28:00,950  
so this is the implicit description

657  
00:28:06,630 --> 00:28:03,760  
this is you describe the things by an

658  
00:28:08,710 --> 00:28:06,640  
equation and and then there is also the

659  
00:28:11,669 --> 00:28:08,720  
explicit description so you have yet

660  
00:28:15,590 --> 00:28:11,679  
another vector space and you have a map

661  
00:28:18,789 --> 00:28:15,600  
let's call it let's call it psi

662  
00:28:20,070 --> 00:28:18,799  
and you say the things here

663  
00:28:22,389 --> 00:28:20,080

that are

664

00:28:23,830 --> 00:28:22,399

well the good things like the points of

665

00:28:27,029 --> 00:28:23,840

the circle

666

00:28:30,149 --> 00:28:27,039

are the image of psy

667

00:28:32,870 --> 00:28:30,159

so you say these are the things that are

668

00:28:34,789 --> 00:28:32,880

the image of psy

669

00:28:37,350 --> 00:28:34,799

okay and this corresponds to the

670

00:28:39,909 --> 00:28:37,360

explicit view

671

00:28:44,310 --> 00:28:39,919

you construct the things you present

672

00:28:47,190 --> 00:28:44,320

them as an image via some operation

673

00:28:52,630 --> 00:28:49,830

coming from some you know maybe

674

00:28:55,269 --> 00:28:52,640

some smaller dimensional space

675

00:28:58,549 --> 00:28:56,830

uh so

676  
00:29:01,029 --> 00:28:58,559  
okay

677  
00:29:05,430 --> 00:29:01,039  
here's a funny thing so

678  
00:29:08,389 --> 00:29:05,440  
if your construction is reasonable

679  
00:29:11,990 --> 00:29:08,399  
then everything you construct

680  
00:29:14,549 --> 00:29:12,000  
solves the equations

681  
00:29:16,070 --> 00:29:14,559  
in other words everything in the image

682  
00:29:19,750 --> 00:29:16,080  
of psy

683  
00:29:20,870 --> 00:29:19,760  
is contained in the kernel of phi

684  
00:29:23,510 --> 00:29:20,880  
so

685  
00:29:25,430 --> 00:29:23,520  
once you have a situation like this you

686  
00:29:27,830 --> 00:29:25,440  
know that you're going to have that the

687  
00:29:33,510 --> 00:29:27,840  
image of psy

688  
00:29:39,190 --> 00:29:36,789

and in fact if you're constructing the

689

00:29:42,549 --> 00:29:39,200

exact same things

690

00:29:45,909 --> 00:29:42,559

then the image of  $i$  will be equal

691

00:29:48,470 --> 00:29:45,919

to the kernel of  $i$  not just contained

692

00:29:52,310 --> 00:29:48,480

okay and then you will be saying that

693

00:29:55,430 --> 00:29:52,320

the situation is exact

694

00:29:57,269 --> 00:29:55,440

things got exactly the things that

695

00:30:00,710 --> 00:29:57,279

you've constructed are the things that

696

00:30:03,110 --> 00:30:00,720

you described by the equations

697

00:30:06,789 --> 00:30:03,120

but that's not always the case

698

00:30:09,590 --> 00:30:06,799

sometimes you have equations defining

699

00:30:12,470 --> 00:30:09,600

something and you want to know did  $i$

700

00:30:17,269 --> 00:30:12,480

construct all the solutions

701

00:30:20,149 --> 00:30:17,279

so sometimes this inclusion is strict

702

00:30:24,789 --> 00:30:20,159

and then you want to measure

703

00:30:27,510 --> 00:30:24,799

by how much or how much did you fail

704

00:30:29,510 --> 00:30:27,520

so how much did you not construct

705

00:30:31,830 --> 00:30:29,520

everything and that's exactly the

706

00:30:34,470 --> 00:30:31,840

difference between the kernel of  $\phi$  and

707

00:30:37,350 --> 00:30:34,480

the image of  $\psi$  and in linear algebra

708

00:30:39,029 --> 00:30:37,360

the difference is quotient so you take

709

00:30:42,149 --> 00:30:39,039

the quotient space

710

00:30:44,870 --> 00:30:42,159

and this is the so-called homology

711

00:30:48,830 --> 00:30:44,880

so somehow homology measures

712

00:30:52,630 --> 00:30:51,269

uh uh

713

00:30:54,470 --> 00:30:52,640

how

714

00:30:55,669 --> 00:30:54,480

good

715

00:30:57,029 --> 00:30:55,679

are

716

00:31:00,950 --> 00:30:57,039

your

717

00:31:06,149 --> 00:31:03,350

did you construct everything or did you

718

00:31:08,630 --> 00:31:06,159

leave some stuff out

719

00:31:10,710 --> 00:31:08,640

is the kernel the implicit the

720

00:31:13,110 --> 00:31:10,720

description this

721

00:31:14,789 --> 00:31:13,120

does it contain more things and then

722

00:31:17,669 --> 00:31:14,799

you've constructed

723

00:31:20,389 --> 00:31:17,679

so somehow homology measures how good

724

00:31:22,230 --> 00:31:20,399

are your constructions and this is true

725

00:31:24,070 --> 00:31:22,240

in general

726

00:31:26,870 --> 00:31:24,080

uh

727

00:31:30,830 --> 00:31:26,880

and and and then there are lots and lots

728

00:31:32,870 --> 00:31:30,840

and lots and lots of specific examples

729

00:31:33,990 --> 00:31:32,880

uh and

730

00:31:36,549 --> 00:31:34,000

uh

731

00:31:38,789 --> 00:31:36,559

to some extent it's a bit of magic i'm

732

00:31:40,389 --> 00:31:38,799

not sure i i can give you a really good

733

00:31:43,909 --> 00:31:40,399

explanation

734

00:31:48,710 --> 00:31:43,919

why there are so many examples and why

735

00:31:51,430 --> 00:31:48,720

so much of mathematics uh end up

736

00:31:56,710 --> 00:31:54,149

having close relationships with with

737

00:31:59,110 --> 00:31:56,720

with uh with homology maybe this is a

738

00:32:01,269 --> 00:31:59,120

partial explanation so

739

00:32:02,950 --> 00:32:01,279

basically you always want to measure how

740

00:32:03,830 --> 00:32:02,960

good is what you've done

741

00:32:05,269 --> 00:32:03,840

so

742

00:32:07,350 --> 00:32:05,279

are you able to talk about what co

743

00:32:09,669 --> 00:32:07,360

homology is and then homology's

744

00:32:11,909 --> 00:32:09,679

relationship to co homology or is that a

745

00:32:13,990 --> 00:32:11,919

whole other can of worms it's another

746

00:32:17,509 --> 00:32:14,000

kind of forms but

747

00:32:19,990 --> 00:32:17,519

in some sense it's not interesting

748

00:32:21,190 --> 00:32:20,000

in in some philosophical sense it's not

749

00:32:27,990 --> 00:32:21,200

interesting

750

00:32:32,230 --> 00:32:30,789

it's essentially the same

751

00:32:34,230 --> 00:32:32,240

so

752

00:32:37,190 --> 00:32:34,240

the difference between a homology and

753

00:32:39,590 --> 00:32:37,200

co-homology more than anything else is a

754

00:32:41,590 --> 00:32:39,600

difference of conventions whether your

755

00:32:42,950 --> 00:32:41,600

map goes from left to right or from

756

00:32:46,549 --> 00:32:42,960

right to left

757

00:32:54,310 --> 00:32:49,590

from this

758

00:32:56,789 --> 00:32:54,320

very imprecise perspective there's

759

00:32:58,710 --> 00:32:56,799

really no difference

760

00:33:00,389 --> 00:32:58,720

professor what do your average days look

761

00:33:03,029 --> 00:33:00,399

like for example do you wake up at the

762

00:33:04,630 --> 00:33:03,039

same time do you drink the same type of

763

00:33:06,149 --> 00:33:04,640

do you drink coffee and it has to be

764

00:33:08,149 --> 00:33:06,159

this particular type of coffee do you

765

00:33:11,350 --> 00:33:08,159

eat a certain breakfast what does it

766

00:33:14,950 --> 00:33:11,360

look like paint the drawer picture

767

00:33:14,960 --> 00:33:18,870

well i'm a lazy bum

768

00:33:22,830 --> 00:33:19,909

and

769

00:33:26,070 --> 00:33:22,840

i'm a believer in the

770

00:33:29,350 --> 00:33:26,080

um you know there was at some point a

771

00:33:31,909 --> 00:33:29,360

revolution right before that uh people

772

00:33:34,470 --> 00:33:31,919

used to work seven days a week uh 12

773

00:33:36,789 --> 00:33:34,480

hours a day or maybe with a short break

774

00:33:38,870 --> 00:33:36,799

on sunday morning

775

00:33:39,990 --> 00:33:38,880

depending which culture you came from i

776  
00:33:43,110 --> 00:33:40,000  
suppose

777  
00:33:45,190 --> 00:33:43,120  
and then at some point there was this uh

778  
00:33:46,070 --> 00:33:45,200  
workers right uh

779  
00:33:47,350 --> 00:33:46,080  
uh

780  
00:33:50,830 --> 00:33:47,360  
revolution

781  
00:33:54,870 --> 00:33:50,840  
and somehow the working week shrunk to

782  
00:33:56,630 --> 00:33:54,880  
uh 40 hours a week or so like five days

783  
00:33:58,149 --> 00:33:56,640  
of eight hours

784  
00:34:01,750 --> 00:33:58,159  
hours a day right

785  
00:34:04,870 --> 00:34:01,760  
and i'm essentially a believer in that

786  
00:34:08,310 --> 00:34:04,880  
uh and furthermore i'm a lazy bum so

787  
00:34:11,669 --> 00:34:08,320  
during my eight hours of work a day

788  
00:34:12,629 --> 00:34:11,679

five days a week i take coffee breaks i

789

00:34:15,909 --> 00:34:12,639

uh

790

00:34:16,869 --> 00:34:15,919

you know browse the web i cheat

791

00:34:18,069 --> 00:34:16,879

uh

792

00:34:21,430 --> 00:34:18,079

um

793

00:34:22,869 --> 00:34:21,440

but anyway you know i wake up at 6 30 i

794

00:34:29,990 --> 00:34:22,879

uh

795

00:34:32,869 --> 00:34:30,000

check my email do all sorts of

796

00:34:36,629 --> 00:34:32,879

unimportant things then uh

797

00:34:39,270 --> 00:34:36,639

around nine usually i start uh working

798

00:34:40,790 --> 00:34:39,280

i work until five or so i'm sorry i'm

799

00:34:44,389 --> 00:34:40,800

very dull

800

00:34:49,430 --> 00:34:47,030

and then i try to have fun for the rest

801  
00:34:51,669 --> 00:34:49,440  
of the day whatever that may be might be

802  
00:34:53,030 --> 00:34:51,679  
during the pandemic it was it is a bit

803  
00:34:56,629 --> 00:34:53,040  
harder

804  
00:34:58,950 --> 00:34:56,639  
and then on the weekends i try to go

805  
00:35:01,510 --> 00:34:58,960  
biking hiking

806  
00:35:03,270 --> 00:35:01,520  
puddling

807  
00:35:05,430 --> 00:35:03,280  
mostly things that don't have to do with

808  
00:35:07,510 --> 00:35:05,440  
work i'm lying a little bit because

809  
00:35:09,510 --> 00:35:07,520  
occasionally there is a reason to work

810  
00:35:11,910 --> 00:35:09,520  
on the weekend and occasionally i do

811  
00:35:14,630 --> 00:35:11,920  
have a meeting with somebody like i have

812  
00:35:16,870 --> 00:35:14,640  
an australian collaborator so often our

813  
00:35:20,109 --> 00:35:16,880

meetings are in the evenings

814

00:35:23,030 --> 00:35:20,119

so i mean i'm i i've given you an

815

00:35:25,030 --> 00:35:23,040

idealized uh story the truth is a little

816

00:35:27,349 --> 00:35:25,040

different is you know

817

00:35:29,750 --> 00:35:27,359

varies when you're working from nine to

818

00:35:31,670 --> 00:35:29,760

five how much of that time is spent

819

00:35:34,150 --> 00:35:31,680

thinking versus reading someone else's

820

00:35:36,710 --> 00:35:34,160

paper versus answering departmental

821

00:35:39,190 --> 00:35:36,720

emails and requests like what is work

822

00:35:41,349 --> 00:35:39,200

because work obviously for a professor

823

00:35:42,630 --> 00:35:41,359

you have to teach you also have to do

824

00:35:45,349 --> 00:35:42,640

research there's

825

00:35:47,510 --> 00:35:45,359

perhaps 10. work is all of that and it

826

00:35:51,430 --> 00:35:47,520

depends on the season so

827

00:35:55,030 --> 00:35:51,440

basically when i teach two courses

828

00:36:00,710 --> 00:35:57,750

there's basically fall spring and summer

829

00:36:03,670 --> 00:36:00,720

you know fall semester spring semester

830

00:36:05,910 --> 00:36:03,680

and summer okay

831

00:36:07,990 --> 00:36:05,920

in the fall in the spring i teach either

832

00:36:10,550 --> 00:36:08,000

two or one course per semester in the

833

00:36:13,349 --> 00:36:10,560

summer i don't teach

834

00:36:14,470 --> 00:36:13,359

so when i teach two courses per semester

835

00:36:15,430 --> 00:36:14,480

that's

836

00:36:18,870 --> 00:36:15,440

almost

837

00:36:21,430 --> 00:36:18,880

have

838

00:36:22,390 --> 00:36:21,440

uh goes into that

839

00:36:25,109 --> 00:36:22,400

uh

840

00:36:27,670 --> 00:36:25,119

and the rest goes into the regular

841

00:36:30,230 --> 00:36:27,680

meetings that i have to keep

842

00:36:32,150 --> 00:36:30,240

so i have several graduate students that

843

00:36:34,390 --> 00:36:32,160

i work with several collaborators and

844

00:36:35,670 --> 00:36:34,400

i'm trying to keep weekly meetings with

845

00:36:37,750 --> 00:36:35,680

them

846

00:36:40,550 --> 00:36:37,760

so there is a certain amount of like

847

00:36:42,550 --> 00:36:40,560

weekly meetings that i have to keep

848

00:36:45,349 --> 00:36:42,560

when i teach one course

849

00:36:47,829 --> 00:36:45,359

uh i have some breathing room and when i

850

00:36:50,550 --> 00:36:47,839

teach nothing namely during the summer

851  
00:36:52,390 --> 00:36:50,560  
then a higher proportion goes into

852  
00:36:54,630 --> 00:36:52,400  
research

853  
00:36:55,750 --> 00:36:54,640  
even in the summer the proportion is not

854  
00:36:57,990 --> 00:36:55,760  
very high

855  
00:37:00,150 --> 00:36:58,000  
firstly is your ideal situation to

856  
00:37:01,589 --> 00:37:00,160  
simply be a research professor i know

857  
00:37:03,589 --> 00:37:01,599  
some professors

858  
00:37:05,670 --> 00:37:03,599  
don't they treat teaching as an aside

859  
00:37:10,950 --> 00:37:05,680  
they don't particularly like to do it

860  
00:37:17,910 --> 00:37:12,950  
well

861  
00:37:25,270 --> 00:37:20,150  
i mean

862  
00:37:33,430 --> 00:37:27,510  
um

863  
00:37:39,430 --> 00:37:36,870

is to support teaching

864

00:37:42,790 --> 00:37:39,440

even the research is so that i will

865

00:37:43,589 --> 00:37:42,800

remain in shape

866

00:37:49,349 --> 00:37:43,599

and

867

00:37:51,349 --> 00:37:49,359

remain in shape so you know if if i do

868

00:37:52,230 --> 00:37:51,359

research i am able to

869

00:37:54,150 --> 00:37:52,240

uh

870

00:37:55,430 --> 00:37:54,160

teach graduate students how to do

871

00:37:57,910 --> 00:37:55,440

research

872

00:37:59,430 --> 00:37:57,920

and then they are

873

00:38:01,510 --> 00:37:59,440

become

874

00:38:05,589 --> 00:38:01,520

stronger mathematicians and can teach

875

00:38:09,030 --> 00:38:05,599

mathematics better so so so so so i even

876

00:38:12,150 --> 00:38:09,040

see researchers mostly uh supporting

877

00:38:16,230 --> 00:38:13,190

so

878

00:38:18,230 --> 00:38:16,240

i definitely wouldn't say that i see

879

00:38:19,750 --> 00:38:18,240

everything as research right i mean

880

00:38:23,109 --> 00:38:19,760

research

881

00:38:25,829 --> 00:38:23,119

again teaching is very significant

882

00:38:28,069 --> 00:38:25,839

well that's the theory

883

00:38:29,910 --> 00:38:28,079

in practice

884

00:38:32,230 --> 00:38:29,920

um

885

00:38:34,790 --> 00:38:32,240

you know waking up every morning and

886

00:38:36,870 --> 00:38:34,800

preparing your class and this marathon

887

00:38:38,230 --> 00:38:36,880

of teaching where you have to prepare

888

00:38:39,670 --> 00:38:38,240

your class

889

00:38:41,990 --> 00:38:39,680

uh you

890

00:38:44,310 --> 00:38:42,000

teach you feel

891

00:38:47,510 --> 00:38:44,320

terrible about the things you missed

892

00:38:49,670 --> 00:38:47,520

during class you don't even have time to

893

00:38:51,829 --> 00:38:49,680

digest it and you have to get ready for

894

00:38:54,150 --> 00:38:51,839

the next class already

895

00:38:55,190 --> 00:38:54,160

so uh

896

00:38:57,670 --> 00:38:55,200

you know

897

00:39:00,069 --> 00:38:57,680

it's very hard

898

00:39:02,950 --> 00:39:00,079

i mean people who haven't done that

899

00:39:06,950 --> 00:39:02,960

don't appreciate how it how hard it is

900

00:39:07,910 --> 00:39:06,960

but it's emotionally very very difficult

901  
00:39:12,390 --> 00:39:07,920  
and

902  
00:39:16,870 --> 00:39:14,790  
you have no idea how much i i'm i'm

903  
00:39:21,589 --> 00:39:16,880  
looking forward to the break so it's not

904  
00:39:25,910 --> 00:39:22,950  
you know i

905  
00:39:27,990 --> 00:39:25,920  
when i teach i want out

906  
00:39:30,550 --> 00:39:28,000  
do you find that to be true even if it's

907  
00:39:33,190 --> 00:39:30,560  
an undergraduate course the reason i ask

908  
00:39:35,589 --> 00:39:33,200  
this is that i imagine as a professor

909  
00:39:37,270 --> 00:39:35,599  
the undergraduate material you could

910  
00:39:39,190 --> 00:39:37,280  
teach with your pinky you don't have to

911  
00:39:40,310 --> 00:39:39,200  
think much about it because you first of

912  
00:39:43,030 --> 00:39:40,320  
all you've mastered it second you've

913  
00:39:45,109 --> 00:39:43,040

taught it for years and years i do not

914

00:39:46,630 --> 00:39:45,119

teach the same class

915

00:39:47,589 --> 00:39:46,640

for years

916

00:39:49,829 --> 00:39:47,599

like

917

00:39:50,950 --> 00:39:49,839

i think the maximum i've ever repeated

918

00:39:54,230 --> 00:39:50,960

the class

919

00:39:56,390 --> 00:39:54,240

uh was like three years

920

00:39:57,430 --> 00:39:56,400

so it's not

921

00:40:02,630 --> 00:39:57,440

but

922

00:40:03,589 --> 00:40:02,640

uh you always have to prepare

923

00:40:06,150 --> 00:40:03,599

uh

924

00:40:08,550 --> 00:40:06,160

you always blunder i always blunder

925

00:40:13,349 --> 00:40:08,560

maybe perfect people don't

926  
00:40:17,589 --> 00:40:15,190  
here and there and then i have to figure

927  
00:40:19,030 --> 00:40:17,599  
out ways out

928  
00:40:22,150 --> 00:40:19,040  
i always

929  
00:40:25,109 --> 00:40:22,160  
find new things to do new ways to do

930  
00:40:27,190 --> 00:40:25,119  
things i always um

931  
00:40:29,829 --> 00:40:27,200  
even when i repeat but essentially but

932  
00:40:32,710 --> 00:40:29,839  
most of the time i don't repeat

933  
00:40:36,710 --> 00:40:32,720  
and the material is sometimes hard you

934  
00:40:41,109 --> 00:40:39,750  
and even when it's not hard

935  
00:40:44,950 --> 00:40:41,119  
so you know

936  
00:40:47,349 --> 00:40:44,960  
on day one of the class

937  
00:40:52,550 --> 00:40:47,359  
you teach of a linear algebra class you

938  
00:40:59,910 --> 00:40:55,430

i obviously know these axioms

939

00:41:02,390 --> 00:40:59,920

right i i obviously um

940

00:41:04,550 --> 00:41:02,400

when i see a vector space

941

00:41:07,430 --> 00:41:04,560

i know it

942

00:41:10,630 --> 00:41:07,440

when i when when you give me a vector

943

00:41:12,950 --> 00:41:10,640

space i know what to do with it

944

00:41:15,349 --> 00:41:12,960

but that's not the same thing

945

00:41:17,589 --> 00:41:15,359

as getting up in front of a class and

946

00:41:18,550 --> 00:41:17,599

listing the axioms

947

00:41:21,349 --> 00:41:18,560

and

948

00:41:24,150 --> 00:41:21,359

making sure that you haven't forgotten

949

00:41:26,790 --> 00:41:24,160

one small axiom somewhere

950

00:41:28,950 --> 00:41:26,800

or that you phrase them perfectly so

951  
00:41:31,990 --> 00:41:28,960  
that even people who have never seen

952  
00:41:33,670 --> 00:41:32,000  
these things before will understand

953  
00:41:36,390 --> 00:41:33,680  
um

954  
00:41:39,829 --> 00:41:36,400  
so i mean even day one of a very basic

955  
00:41:41,270 --> 00:41:39,839  
class uh requires preparation

956  
00:41:42,710 --> 00:41:41,280  
we're gonna talk about mathematical

957  
00:41:45,190 --> 00:41:42,720  
techniques

958  
00:41:46,470 --> 00:41:45,200  
in fact i believe when we emailed you

959  
00:41:48,630 --> 00:41:46,480  
said you don't like the emphasis on

960  
00:41:50,790 --> 00:41:48,640  
theorems and proofs you like

961  
00:41:52,230 --> 00:41:50,800  
well we can talk about that later

962  
00:41:54,309 --> 00:41:52,240  
as for

963  
00:41:55,750 --> 00:41:54,319

teaching techniques i'm curious what

964

00:41:58,870 --> 00:41:55,760

have you gleaned what have you found to

965

00:42:01,349 --> 00:41:58,880

be productive and perhaps even some

966

00:42:03,670 --> 00:42:01,359

behaviors you find to be unproductive

967

00:42:07,270 --> 00:42:03,680

that you see other people other teachers

968

00:42:11,270 --> 00:42:09,750

i mean there is so much

969

00:42:13,270 --> 00:42:11,280

uh

970

00:42:14,390 --> 00:42:13,280

you know starting from

971

00:42:19,510 --> 00:42:14,400

com

972

00:42:22,069 --> 00:42:19,520

make sure that you're heard

973

00:42:25,109 --> 00:42:22,079

right if the classroom is large and you

974

00:42:27,270 --> 00:42:25,119

speak without a microphone

975

00:42:29,109 --> 00:42:27,280

uh people in the back are not going to

976

00:42:31,190 --> 00:42:29,119

hear you and then

977

00:42:33,910 --> 00:42:31,200

they're not going to follow

978

00:42:36,710 --> 00:42:33,920

uh make sure that you can be seen

979

00:42:39,510 --> 00:42:36,720

so if you write with a tiny you know if

980

00:42:40,870 --> 00:42:39,520

you write tiny letters with a faded

981

00:42:42,309 --> 00:42:40,880

chalk

982

00:42:46,950 --> 00:42:42,319

uh

983

00:42:48,710 --> 00:42:46,960

the class is a failure no matter what

984

00:42:50,870 --> 00:42:48,720

you say

985

00:42:52,150 --> 00:42:50,880

and then there are uh higher level

986

00:42:56,550 --> 00:42:52,160

things and

987

00:42:58,710 --> 00:42:56,560

basically everything should be motivated

988

00:43:01,349 --> 00:42:58,720

so you know i mentioned the first class

989

00:43:03,910 --> 00:43:01,359

of a linear the first class uh in a

990

00:43:07,510 --> 00:43:03,920

linear algebra course

991

00:43:09,510 --> 00:43:07,520

okay so you can give by uh you can give

992

00:43:12,710 --> 00:43:09,520

by this class

993

00:43:15,430 --> 00:43:12,720

by saying uh you can start this class by

994

00:43:18,990 --> 00:43:15,440

saying let  $f$  be

995

00:43:21,990 --> 00:43:20,870

essent

996

00:43:23,510 --> 00:43:22,000

$v$

997

00:43:24,950 --> 00:43:23,520

is

998

00:43:28,230 --> 00:43:24,960

called

999

00:43:30,710 --> 00:43:28,240

a vector space if

1000

00:43:33,430 --> 00:43:30,720

and then you can write property you know

1001

00:43:35,910 --> 00:43:33,440

operations and properties and you know

1002

00:43:37,190 --> 00:43:35,920

you write item number one to item number

1003

00:43:44,550 --> 00:43:37,200

15

1004

00:43:47,510 --> 00:43:44,560

like alpha times beta times a vector

1005

00:43:49,589 --> 00:43:47,520

you know whatever so one of the axioms

1006

00:43:53,990 --> 00:43:49,599

of a vector field

1007

00:43:55,349 --> 00:43:54,000

okay of a vector sorry a vector space

1008

00:43:58,390 --> 00:43:55,359

uh

1009

00:44:00,390 --> 00:43:58,400

and then the question arises why

1010

00:44:03,910 --> 00:44:00,400

and who cares

1011

00:44:05,829 --> 00:44:03,920

right right okay so if you start your

1012

00:44:08,710 --> 00:44:05,839

class this way

1013

00:44:09,829 --> 00:44:08,720

people aren't going to like it so before

1014

00:44:13,910 --> 00:44:09,839

this

1015

00:44:16,230 --> 00:44:13,920

there has to be a a little section

1016

00:44:18,069 --> 00:44:16,240

i don't know here

1017

00:44:21,190 --> 00:44:18,079

where you explain

1018

00:44:27,349 --> 00:44:24,630

well for such and such reasons we care

1019

00:44:31,270 --> 00:44:27,359

about vector spaces so there has to be

1020

00:44:34,470 --> 00:44:32,230

okay

1021

00:44:37,430 --> 00:44:34,480

and uh

1022

00:44:40,550 --> 00:44:37,440

and that's true

1023

00:44:42,230 --> 00:44:40,560

not only in the first class of the first

1024

00:44:43,910 --> 00:44:42,240

um

1025

00:44:47,270 --> 00:44:43,920

uh

1026

00:44:49,430 --> 00:44:47,280

of a linear algebra of course it's true

1027

00:44:51,990 --> 00:44:49,440

in every class whenever you say

1028

00:44:53,670 --> 00:44:52,000

something there has to be a reason

1029

00:44:55,990 --> 00:44:53,680

and the people who

1030

00:44:59,109 --> 00:44:56,000

um

1031

00:45:00,950 --> 00:44:59,119

who are listening to you uh

1032

00:45:04,309 --> 00:45:00,960

should know that you've thought about it

1033

00:45:06,150 --> 00:45:04,319

should know that you

1034

00:45:07,670 --> 00:45:06,160

that you're telling them these things

1035

00:45:08,870 --> 00:45:07,680

for a reason

1036

00:45:09,750 --> 00:45:08,880

okay

1037

00:45:12,710 --> 00:45:09,760

and

1038

00:45:13,910 --> 00:45:12,720

uh that's often omitted

1039

00:45:16,790 --> 00:45:13,920

it's often

1040

00:45:19,109 --> 00:45:16,800

too easy to just follow the definitions

1041

00:45:21,270 --> 00:45:19,119

in the theorems and never say what

1042

00:45:23,190 --> 00:45:21,280

they're good for

1043

00:45:25,030 --> 00:45:23,200

and um

1044

00:45:29,030 --> 00:45:25,040

and not only you should say these things

1045

00:45:29,040 --> 00:45:34,230

likewise when you write a proof uh

1046

00:45:38,950 --> 00:45:37,589

it's often easy to

1047

00:45:41,589 --> 00:45:38,960

well to

1048

00:45:43,030 --> 00:45:41,599

to so i mean often there is a picture

1049

00:45:47,589 --> 00:45:43,040

behind that proof

1050

00:45:49,750 --> 00:45:47,599

the proof is telling some story and you

1051  
00:45:52,550 --> 00:45:49,760  
and you want the picture of that story

1052  
00:45:55,349 --> 00:45:52,560  
in the minds of the students

1053  
00:45:57,270 --> 00:45:55,359  
but but but but it's often too easy to

1054  
00:45:59,670 --> 00:45:57,280  
reduce it to a

1055  
00:46:02,470 --> 00:45:59,680  
list of formulas

1056  
00:46:03,990 --> 00:46:02,480  
or a list of statements so a higher

1057  
00:46:06,230 --> 00:46:04,000  
level thing is to make sure that

1058  
00:46:07,990 --> 00:46:06,240  
everything is motivated

1059  
00:46:10,710 --> 00:46:08,000  
what else what's another higher level

1060  
00:46:12,950 --> 00:46:10,720  
aspect of teaching

1061  
00:46:15,349 --> 00:46:12,960  
that you find is a common mistake among

1062  
00:46:18,150 --> 00:46:15,359  
the teachers that you see

1063  
00:46:23,190 --> 00:46:20,950

i think maybe this is the biggest

1064

00:46:25,510 --> 00:46:23,200

not showing the motivation clearly

1065

00:46:28,470 --> 00:46:25,520

enough

1066

00:46:30,790 --> 00:46:28,480

and by the way

1067

00:46:33,750 --> 00:46:30,800

uh

1068

00:46:37,349 --> 00:46:33,760

that's part of the reason why research

1069

00:46:39,109 --> 00:46:37,359

is a necessary part of teaching

1070

00:46:41,670 --> 00:46:39,119

because

1071

00:46:47,670 --> 00:46:45,430

you have to know the motivation

1072

00:46:51,270 --> 00:46:47,680

you know you can say

1073

00:46:53,670 --> 00:46:51,280

vector spaces are a great thing

1074

00:46:57,109 --> 00:46:53,680

unless you've actually worked with them

1075

00:46:59,589 --> 00:46:57,119

unless you've actually seen them used

1076

00:47:02,870 --> 00:46:59,599

so maybe vector spaces are good and are

1077

00:47:04,069 --> 00:47:02,880

easy enough so that you can um

1078

00:47:05,910 --> 00:47:04,079

uh

1079

00:47:07,990 --> 00:47:05,920

um

1080

00:47:10,069 --> 00:47:08,000

you know by third year you understand

1081

00:47:12,790 --> 00:47:10,079

why you why you learned about them in

1082

00:47:17,589 --> 00:47:15,190

but if you want to be able to say

1083

00:47:19,670 --> 00:47:17,599

something intelligent about homology you

1084

00:47:22,829 --> 00:47:19,680

have to have used it

1085

00:47:25,510 --> 00:47:22,839

the only way to use it is in research

1086

00:47:27,030 --> 00:47:25,520

so uh

1087

00:47:29,030 --> 00:47:27,040

uh

1088

00:47:33,670 --> 00:47:29,040

so that's what i meant by you have to be

1089

00:47:35,190 --> 00:47:33,680

in shape being in shape also means

1090

00:47:38,950 --> 00:47:35,200

remember what

1091

00:47:41,109 --> 00:47:38,960

what can be done with these things

1092

00:47:42,390 --> 00:47:41,119

do you find that you're more creative as

1093

00:47:44,790 --> 00:47:42,400

you get older

1094

00:47:50,790 --> 00:47:44,800

or that your creativity peaked at a

1095

00:47:55,190 --> 00:47:52,950

i you

1096

00:47:57,190 --> 00:47:55,200

you know i i wish i could answer the

1097

00:47:59,430 --> 00:47:57,200

truth is that

1098

00:48:04,069 --> 00:47:59,440

i don't really remember

1099

00:48:09,270 --> 00:48:06,790

it's very hard to remember myself at any

1100

00:48:11,270 --> 00:48:09,280

other age

1101

00:48:13,349 --> 00:48:11,280

so i mean certainly

1102

00:48:15,910 --> 00:48:13,359

um

1103

00:48:18,470 --> 00:48:15,920

i have matured

1104

00:48:21,829 --> 00:48:18,480

so the little i can remember from 20 or

1105

00:48:22,630 --> 00:48:21,839

30 years ago um

1106

00:48:30,309 --> 00:48:22,640

is

1107

00:48:38,069 --> 00:48:34,069

i'm more systematic perhaps

1108

00:48:45,109 --> 00:48:41,030

am i smarter am i more creative am i

1109

00:48:46,150 --> 00:48:45,119

stupider am i less creative i'm not sure

1110

00:48:47,750 --> 00:48:46,160

what do you mean when you say you're

1111

00:48:48,950 --> 00:48:47,760

more systematic now can you give an

1112

00:48:52,549 --> 00:48:48,960

example of how you would look at a

1113

00:49:01,190 --> 00:48:52,559

certain problem now or solve it versus

1114

00:49:06,230 --> 00:49:03,750

and also a sub question do you see being

1115

00:49:08,309 --> 00:49:06,240

systematic as a good thing or do you see

1116

00:49:10,790 --> 00:49:08,319

there being innovation in being

1117

00:49:12,309 --> 00:49:10,800

disorganized or creativity embedded

1118

00:49:16,790 --> 00:49:12,319

there

1119

00:49:25,349 --> 00:49:16,800

no systematic is generally better

1120

00:49:31,030 --> 00:49:26,549

much

1121

00:49:32,790 --> 00:49:31,040

more into the low hanging fruits

1122

00:49:36,790 --> 00:49:32,800

so

1123

00:49:39,910 --> 00:49:38,150

but

1124

00:49:45,510 --> 00:49:39,920

[Music]

1125

00:49:45,520 --> 00:49:50,470

i'd uh

1126  
00:49:54,470 --> 00:49:52,950  
like wait for opportunities and and then

1127  
00:49:56,829 --> 00:49:54,480  
use them

1128  
00:50:02,470 --> 00:49:59,109  
uh and

1129  
00:50:07,270 --> 00:50:05,190  
now it's much more i have a long-term

1130  
00:50:08,150 --> 00:50:07,280  
goal

1131  
00:50:12,950 --> 00:50:08,160  
uh

1132  
00:50:16,470 --> 00:50:12,960  
a theory of something

1133  
00:50:18,870 --> 00:50:16,480  
you know your your your uh

1134  
00:50:21,750 --> 00:50:18,880  
podcast is a theory of everything right

1135  
00:50:24,390 --> 00:50:21,760  
i just want a theory of something

1136  
00:50:27,430 --> 00:50:24,400  
so i want a theory of something because

1137  
00:50:29,349 --> 00:50:27,440  
i i feel for various reasons that it

1138  
00:50:30,549 --> 00:50:29,359

ought to be there

1139

00:50:31,080 --> 00:50:30,559

and then i

1140

00:50:32,230 --> 00:50:31,090

um

1141

00:50:34,549 --> 00:50:32,240

[Music]

1142

00:50:35,589 --> 00:50:34,559

worked very hard

1143

00:50:38,069 --> 00:50:35,599

on

1144

00:50:40,950 --> 00:50:38,079

well very hard to my standards i already

1145

00:50:43,910 --> 00:50:40,960

admitted being a bomb so um

1146

00:50:44,870 --> 00:50:43,920

you know i i worked at least for a long

1147

00:50:49,030 --> 00:50:44,880

time

1148

00:50:52,150 --> 00:50:49,040

uh trying to find that theory

1149

00:50:54,630 --> 00:50:52,160

you know even assist even even at a very

1150

00:50:55,430 --> 00:50:54,640

at a much lower level

1151

00:50:56,309 --> 00:50:55,440

uh

1152

00:51:00,470 --> 00:50:56,319

so

1153

00:51:03,910 --> 00:51:01,349

uh

1154

00:51:05,750 --> 00:51:03,920

you know so you know math theorems and

1155

00:51:09,270 --> 00:51:05,760

proofs were

1156

00:51:11,349 --> 00:51:09,280

pressed into my brain was essentially an

1157

00:51:13,829 --> 00:51:11,359

external process right so i went to

1158

00:51:15,910 --> 00:51:13,839

classes and people pushed theorems into

1159

00:51:17,030 --> 00:51:15,920

my brain

1160

00:51:19,670 --> 00:51:17,040

and

1161

00:51:25,990 --> 00:51:20,829

some of

1162

00:51:28,790 --> 00:51:26,000

them seemed like complete formalities

1163

00:51:34,309 --> 00:51:31,990

a sequence of deductions

1164

00:51:36,870 --> 00:51:34,319

uh that i could have that i could

1165

00:51:39,430 --> 00:51:36,880

memorize and i could

1166

00:51:43,670 --> 00:51:39,440

verify

1167

00:51:46,790 --> 00:51:43,680

but were essentially created by aliens

1168

00:51:47,990 --> 00:51:46,800

you know i i had no idea how they came

1169

00:51:51,109 --> 00:51:48,000

to be

1170

00:51:52,230 --> 00:51:51,119

right in some theorems

1171

00:51:53,670 --> 00:51:52,240

uh

1172

00:51:54,790 --> 00:51:53,680

immediately

1173

00:51:57,270 --> 00:51:54,800

uh

1174

00:51:59,190 --> 00:51:57,280

became a picture i immediately

1175

00:52:01,030 --> 00:51:59,200

understood

1176  
00:52:03,030 --> 00:52:01,040  
uh

1177  
00:52:08,230 --> 00:52:03,040  
that

1178  
00:52:11,109 --> 00:52:08,240  
geometric reality

1179  
00:52:13,349 --> 00:52:11,119  
okay describe

1180  
00:52:14,790 --> 00:52:13,359  
i i i i could see the intuition behind

1181  
00:52:16,390 --> 00:52:14,800  
the proof

1182  
00:52:17,990 --> 00:52:16,400  
it's not always geometric though it's

1183  
00:52:19,990 --> 00:52:18,000  
just you see the internet necessarily

1184  
00:52:22,470 --> 00:52:20,000  
geometric i mean but i could see somehow

1185  
00:52:24,870 --> 00:52:22,480  
the motivation the the the i i could

1186  
00:52:27,270 --> 00:52:24,880  
imagine how the proof was discovered

1187  
00:52:29,910 --> 00:52:27,280  
i think i i i would get the feeling that

1188  
00:52:31,910 --> 00:52:29,920

i understood the proof and there and and

1189

00:52:34,069 --> 00:52:31,920

that was essentially a dichotomy some

1190

00:52:37,270 --> 00:52:34,079

pictures some proofs

1191

00:52:39,190 --> 00:52:37,280

or some concept were of that type

1192

00:52:42,710 --> 00:52:39,200

made by aliens

1193

00:52:44,829 --> 00:52:42,720

and pushed into my brain by professors

1194

00:52:50,230 --> 00:52:44,839

and other

1195

00:52:53,349 --> 00:52:50,240

um uh concepts theorems proofs whatever

1196

00:52:56,390 --> 00:52:53,359

were clearly intuitive and made sense

1197

00:52:58,950 --> 00:52:56,400

and and i understood them

1198

00:53:01,270 --> 00:52:58,960

uh and that was it that was the world

1199

00:53:04,870 --> 00:53:01,280

there was this and there were those

1200

00:53:07,109 --> 00:53:04,880

and then sometime later in second year i

1201

00:53:09,750 --> 00:53:07,119

actually did my ba very very very

1202

00:53:12,069 --> 00:53:09,760

quickly so uh basically

1203

00:53:13,910 --> 00:53:12,079

i did it in essentially two years

1204

00:53:15,750 --> 00:53:13,920

so when i say second year you should

1205

00:53:18,470 --> 00:53:15,760

compare it maybe with year three and

1206

00:53:22,309 --> 00:53:18,480

four of um most students

1207

00:53:23,990 --> 00:53:22,319

so somewhere later in late in my studies

1208

00:53:27,589 --> 00:53:24,000

i realized

1209

00:53:30,630 --> 00:53:27,599

that if i think harder

1210

00:53:34,069 --> 00:53:30,640

about the theorems that

1211

00:53:35,349 --> 00:53:34,079

uh or the concepts that appear to be

1212

00:53:37,829 --> 00:53:35,359

alien

1213

00:53:40,870 --> 00:53:37,839

then sooner or later

1214

00:53:43,109 --> 00:53:40,880

i see the picture behind them sooner or

1215

00:53:43,910 --> 00:53:43,119

later i realize

1216

00:53:44,950 --> 00:53:43,920

uh

1217

00:53:46,790 --> 00:53:44,960

that

1218

00:53:47,750 --> 00:53:46,800

i i'm able to move them to the other

1219

00:53:53,109 --> 00:53:47,760

class

1220

00:53:56,950 --> 00:53:53,119

and and and um

1221

00:53:58,069 --> 00:53:56,960

and understand it and understood

1222

00:54:01,349 --> 00:53:58,079

and

1223

00:54:02,549 --> 00:54:01,359

it

1224

00:54:09,829 --> 00:54:02,559

so

1225

00:54:12,549 --> 00:54:09,839

i may learn it from a book that

1226

00:54:15,030 --> 00:54:12,559

describes it as a formula

1227

00:54:18,150 --> 00:54:15,040

okay and then i'll struggle to see the

1228

00:54:20,470 --> 00:54:18,160

intuition behind the formula

1229

00:54:23,510 --> 00:54:20,480

and so even at that level it's it's

1230

00:54:27,990 --> 00:54:23,520

something that took learning

1231

00:54:33,670 --> 00:54:31,109

again when i got to the university

1232

00:54:36,069 --> 00:54:33,680

you know when i when i was in first year

1233

00:54:38,950 --> 00:54:36,079

i took classes and i got good gr good

1234

00:54:42,150 --> 00:54:38,960

grades in in in all of them

1235

00:54:46,230 --> 00:54:43,670

and nevertheless

1236

00:54:51,190 --> 00:54:48,470

there was a point where

1237

00:54:53,270 --> 00:54:51,200

where things became better where where i

1238

00:54:55,990 --> 00:54:53,280

realize i can actually

1239

00:54:58,549 --> 00:54:56,000

understand everything

1240

00:55:00,069 --> 00:54:58,559

and not just repeat everything

1241

00:55:01,750 --> 00:55:00,079

and that came later

1242

00:55:03,829 --> 00:55:01,760

what does that process of finding the

1243

00:55:05,430 --> 00:55:03,839

intuition behind let's say a formula

1244

00:55:07,349 --> 00:55:05,440

that before you

1245

00:55:10,069 --> 00:55:07,359

previously simply had to memorize as

1246

00:55:12,150 --> 00:55:10,079

handed down from the gods or the aliens

1247

00:55:14,470 --> 00:55:12,160

what does that process look like the

1248

00:55:16,069 --> 00:55:14,480

process of finding the intuition does it

1249

00:55:17,750 --> 00:55:16,079

look like

1250

00:55:20,870 --> 00:55:17,760

i'm sure it's a variety of these but

1251  
00:55:23,190 --> 00:55:20,880  
does it majorly look like you copy it

1252  
00:55:24,549 --> 00:55:23,200  
down with the pen and paper precisely

1253  
00:55:26,549 --> 00:55:24,559  
and then you draw arrows and you say

1254  
00:55:28,870 --> 00:55:26,559  
okay so what's an example of this what's

1255  
00:55:30,549 --> 00:55:28,880  
a counter example of this or is it you

1256  
00:55:32,710 --> 00:55:30,559  
go on a bike ride and you keep thinking

1257  
00:55:34,630 --> 00:55:32,720  
about it what does that process look

1258  
00:55:37,109 --> 00:55:34,640  
like perhaps it would be edifying if you

1259  
00:55:39,589 --> 00:55:37,119  
took a specific example but if you can't

1260  
00:55:42,309 --> 00:55:39,599  
then just give the broad strokes

1261  
00:55:45,910 --> 00:55:44,069  
you know what it what does it look like

1262  
00:55:48,390 --> 00:55:45,920  
from the outside from the outside it

1263  
00:55:51,270 --> 00:55:48,400

looks like i'm sitting on my chair and

1264

00:55:52,710 --> 00:55:51,280

staring into the into infinity

1265

00:55:54,710 --> 00:55:52,720

right or

1266

00:55:57,750 --> 00:55:54,720

sitting on my balcony and looking at the

1267

00:55:57,760 --> 00:56:16,230

what does it look like inside

1268

00:56:16,240 --> 00:56:32,549

it's very hard to answer without

1269

00:56:38,470 --> 00:56:35,109

without going through specific examples

1270

00:56:40,870 --> 00:56:38,480

and the specific examples are

1271

00:56:43,030 --> 00:56:40,880

far too complex or i i don't know if

1272

00:56:45,270 --> 00:56:43,040

they are far too complex but they fit in

1273

00:56:48,470 --> 00:56:45,280

a math class

1274

00:56:50,630 --> 00:56:48,480

and the other thing is um

1275

00:56:52,630 --> 00:56:50,640

you will never see these examples in my

1276

00:56:55,190 --> 00:56:52,640

classes because when i teach something i

1277

00:56:56,470 --> 00:56:55,200

try to motivate it

1278

00:56:59,349 --> 00:56:56,480

okay

1279

00:57:01,510 --> 00:56:59,359

so you will not see the alternative

1280

00:57:04,630 --> 00:57:01,520

okay you will see the motivated way of

1281

00:57:08,150 --> 00:57:04,640

explaining uh uh the

1282

00:57:12,789 --> 00:57:08,160

implicit function theorem or the uh

1283

00:57:15,589 --> 00:57:12,799

change of variables formula for multi

1284

00:57:21,270 --> 00:57:15,599

integrals right you'll see the motivated

1285

00:57:24,829 --> 00:57:23,030

i will not be showing you the

1286

00:57:27,430 --> 00:57:24,839

unmotivated

1287

00:57:29,349 --> 00:57:27,440

formulas for you much of the time when

1288

00:57:32,789 --> 00:57:29,359

it's difficult for you to understand a

1289

00:57:34,150 --> 00:57:32,799

proof or a theorem or concept is it

1290

00:57:42,710 --> 00:57:34,160

most of the time because it was

1291

00:57:47,030 --> 00:57:45,109

well the intuition is not explained

1292

00:57:50,390 --> 00:57:47,040

often

1293

00:57:54,549 --> 00:57:50,400

so in textbooks

1294

00:57:54,559 --> 00:58:06,829

often the intuition is not explained

1295

00:58:10,549 --> 00:58:08,549

now

1296

00:58:12,309 --> 00:58:10,559

some intuition is just getting used to

1297

00:58:15,270 --> 00:58:12,319

the concepts

1298

00:58:18,630 --> 00:58:15,280

so sometimes intuition is not is not

1299

00:58:22,390 --> 00:58:20,470

it's just playing around until you're

1300

00:58:23,829 --> 00:58:22,400

used to it

1301

00:58:24,870 --> 00:58:23,839

you know

1302

00:58:27,190 --> 00:58:24,880

uh

1303

00:58:30,470 --> 00:58:27,200

you've just landed in a foreign city

1304

00:58:31,589 --> 00:58:30,480

you've just landed in athens

1305

00:58:33,430 --> 00:58:31,599

uh

1306

00:58:37,109 --> 00:58:33,440

your hotel

1307

00:58:39,670 --> 00:58:37,119

is two kilometers from the acropolis

1308

00:58:40,950 --> 00:58:39,680

uh you got there at night you wake up in

1309

00:58:42,630 --> 00:58:40,960

the morning you want to go to the

1310

00:58:43,990 --> 00:58:42,640

acropolis

1311

00:58:47,030 --> 00:58:44,000

you

1312

00:58:49,990 --> 00:58:47,040

punch acropolis into google maps

1313

00:58:52,230 --> 00:58:50,000

and google maps tells you

1314

00:58:54,069 --> 00:58:52,240

you know go left go right go straight go

1315

00:58:56,390 --> 00:58:54,079

left go right and here's the cro

1316

00:58:58,950 --> 00:58:56,400

acropolis okay you follow the

1317

00:59:02,069 --> 00:58:58,960

instructions

1318

00:59:05,510 --> 00:59:02,079

you didn't learn atoms

1319

00:59:07,990 --> 00:59:05,520

you've learned the way to the acropolis

1320

00:59:10,230 --> 00:59:08,000

uh to learn athens

1321

00:59:12,870 --> 00:59:10,240

uh

1322

00:59:15,990 --> 00:59:12,880

in the afternoon after the acropolis you

1323

00:59:17,910 --> 00:59:16,000

have to wander around

1324

00:59:20,870 --> 00:59:17,920

uh and then you have to continue

1325

00:59:23,270 --> 00:59:20,880

wandering around for the next two weeks

1326  
00:59:26,950 --> 00:59:23,280  
and then maybe you're starting to have a

1327  
00:59:29,670 --> 00:59:26,960  
grasp of what athens is

1328  
00:59:31,589 --> 00:59:29,680  
so there is similar

1329  
00:59:33,589 --> 00:59:31,599  
there is something similar in in

1330  
00:59:36,789 --> 00:59:33,599  
mathematics

1331  
00:59:38,950 --> 00:59:36,799  
okay or in science or in fact in every

1332  
00:59:42,470 --> 00:59:38,960  
field of learning okay i mean but in

1333  
00:59:44,870 --> 00:59:42,480  
mathematics you know um

1334  
00:59:46,630 --> 00:59:44,880  
uh you don't

1335  
00:59:48,309 --> 00:59:46,640  
uh

1336  
00:59:56,789 --> 00:59:48,319  
learn

1337  
00:59:58,390 --> 00:59:56,799  
most interesting result result in a

1338  
01:00:01,589 --> 00:59:58,400

certain field

1339

01:00:04,309 --> 01:00:01,599

you haven't learned the field

1340

01:00:07,109 --> 01:00:04,319

okay you've just learned and especially

1341

01:00:09,109 --> 01:00:07,119

if you if you follow the directions by

1342

01:00:10,870 --> 01:00:09,119

somebody else

1343

01:00:12,870 --> 01:00:10,880

okay

1344

01:00:14,390 --> 01:00:12,880

the learning happens if you wander

1345

01:00:16,230 --> 01:00:14,400

around later

1346

01:00:18,230 --> 01:00:16,240

and in a way you have to do it on your

1347

01:00:20,710 --> 01:00:18,240

own

1348

01:00:22,470 --> 01:00:20,720

right this this wandering around so

1349

01:00:25,430 --> 01:00:22,480

wandering around in mathematics means

1350

01:00:26,150 --> 01:00:25,440

you experiment you change the conditions

1351

01:00:34,069 --> 01:00:26,160

you

1352

01:00:40,950 --> 01:00:34,079

situations

1353

01:00:45,190 --> 01:00:43,030

well so i mean

1354

01:00:47,750 --> 01:00:45,200

like part of tourism you do with a tour

1355

01:00:49,990 --> 01:00:47,760

guide and part of an and a part you have

1356

01:00:56,470 --> 01:00:50,000

to do on your own on your own

1357

01:00:56,480 --> 01:01:02,069

uh so so so so some part of uh

1358

01:01:09,109 --> 01:01:04,549

being systematic if you wish is doing

1359

01:01:12,630 --> 01:01:09,119

this on my own thing in a systematic way

1360

01:01:15,190 --> 01:01:12,640

okay this realization that i can just

1361

01:01:18,309 --> 01:01:15,200

jump into a topic by

1362

01:01:19,589 --> 01:01:18,319

following somebody's guidance

1363

01:01:22,789 --> 01:01:19,599

1364

01:01:26,630 --> 01:01:22,799

i must sit down and think and ask myself

1365

01:01:30,309 --> 01:01:26,640

many many many many more questions and

1366

01:01:34,230 --> 01:01:30,319

go on side tracks and until until it's

1367

01:01:38,470 --> 01:01:36,470

now in this example

1368

01:01:40,950 --> 01:01:38,480

let me let me see if i'm understanding

1369

01:01:42,390 --> 01:01:40,960

it correctly let's say athens athens the

1370

01:01:44,390 --> 01:01:42,400

city and then you have the acropolis

1371

01:01:45,589 --> 01:01:44,400

which is a landmark so that's almost

1372

01:01:47,430 --> 01:01:45,599

like a landmark theorem and then the

1373

01:01:48,549 --> 01:01:47,440

directions are the proof and the steps

1374

01:01:49,829 --> 01:01:48,559

to get there

1375

01:01:51,349 --> 01:01:49,839

would you say and you're saying the

1376

01:01:52,789 --> 01:01:51,359

learning comes from the wandering would

1377

01:01:55,510 --> 01:01:52,799

you say that when you first land in

1378

01:01:57,109 --> 01:01:55,520

athens you should wander or should you

1379

01:01:58,470 --> 01:01:57,119

learn the major landmarks and the

1380

01:02:00,549 --> 01:01:58,480

directions to get there perhaps

1381

01:02:02,230 --> 01:02:00,559

forgetting the directions you just get

1382

01:02:04,870 --> 01:02:02,240

yourself there so that you see what the

1383

01:02:06,630 --> 01:02:04,880

landmarks are like later you wonder the

1384

01:02:08,309 --> 01:02:06,640

analogy would be you learn the major

1385

01:02:09,670 --> 01:02:08,319

theorems and then later you try and get

1386

01:02:11,589 --> 01:02:09,680

the intuition by playing around with

1387

01:02:15,190 --> 01:02:11,599

them or do you play from the get-go i

1388

01:02:17,430 --> 01:02:15,200

mean there has to be a bit of both

1389

01:02:20,069 --> 01:02:17,440

uh basically you know if you land in

1390

01:02:23,270 --> 01:02:20,079

athens and start wondering randomly you

1391

01:02:26,470 --> 01:02:23,280

end up you may end up wandering randomly

1392

01:02:29,029 --> 01:02:26,480

in a completely uninteresting direction

1393

01:02:31,270 --> 01:02:29,039

plus there is a fear factor

1394

01:02:32,870 --> 01:02:31,280

and you know you may feared about

1395

01:02:35,270 --> 01:02:32,880

neighborhoods

1396

01:02:37,829 --> 01:02:35,280

interesting but but but but there

1397

01:02:39,670 --> 01:02:37,839

actually is an analog an analogy in

1398

01:02:40,950 --> 01:02:39,680

mathematics or

1399

01:02:45,910 --> 01:02:40,960

it

1400

01:02:48,870 --> 01:02:45,920

things and the guidance

1401

01:02:50,950 --> 01:02:48,880

can help you overcome the fear but maybe

1402

01:02:53,430 --> 01:02:50,960

fear is not the right way i mean think

1403

01:02:55,270 --> 01:02:53,440

that you have to explore atoms when when

1404

01:02:57,190 --> 01:02:55,280

it's dark

1405

01:02:59,589 --> 01:02:57,200

okay so you simply don't know which way

1406

01:03:01,589 --> 01:02:59,599

to go you just land

1407

01:03:03,750 --> 01:03:01,599

you know i tell you think about vector

1408

01:03:05,589 --> 01:03:03,760

spaces you have no idea what good

1409

01:03:08,789 --> 01:03:05,599

questions to ask are what are the good

1410

01:03:12,630 --> 01:03:09,750

and

1411

01:03:17,670 --> 01:03:14,150

[Music]

1412

01:03:19,670 --> 01:03:17,680

so you need guidance

1413

01:03:21,349 --> 01:03:19,680

or else you will be stuck in one

1414

01:03:23,430 --> 01:03:21,359

neighborhood and never realize that

1415

01:03:25,990 --> 01:03:23,440

there is more than that

1416

01:03:27,829 --> 01:03:26,000

but you know after the guidance took you

1417

01:03:31,829 --> 01:03:27,839

from here to there

1418

01:03:37,510 --> 01:03:34,870

go back and explore and explore more and

1419

01:03:40,630 --> 01:03:37,520

explore more and until you until it's a

1420

01:03:42,549 --> 01:03:40,640

solid and not just a single path

1421

01:03:44,950 --> 01:03:42,559

so you have to do your own finding path

1422

01:03:48,710 --> 01:03:44,960

integral over the space of mathematical

1423

01:03:50,069 --> 01:03:48,720

ideas there is a bit of that yes

1424

01:03:53,430 --> 01:03:50,079

what's your greatest strength as a

1425

01:03:56,549 --> 01:03:53,440

mathematician or some of your strengths

1426

01:04:00,069 --> 01:03:56,559

who says i have strengthens

1427

01:04:04,309 --> 01:04:02,390

i'm a lazy bum

1428

01:04:06,069 --> 01:04:04,319

are you being modest when you say that

1429

01:04:07,829 --> 01:04:06,079

because i imagine someone who has an

1430

01:04:09,750 --> 01:04:07,839

accelerated degree two-year degree that

1431

01:04:11,510 --> 01:04:09,760

should ordinarily take four years it's

1432

01:04:14,069 --> 01:04:11,520

not as if you spend the majority of your

1433

01:04:16,710 --> 01:04:14,079

time playing video games and

1434

01:04:20,069 --> 01:04:16,720

and being on industrious oh you'll be

1435

01:04:23,430 --> 01:04:21,589

uh

1436

01:04:29,349 --> 01:04:23,440

i mean of course i didn't play video

1437

01:04:35,349 --> 01:04:33,109

you know video video games came later

1438

01:04:36,470 --> 01:04:35,359

uh

1439

01:04:39,349 --> 01:04:36,480

but

1440

01:04:40,950 --> 01:04:39,359

i definitely killed a lot of time

1441

01:04:43,430 --> 01:04:40,960

so who are you comparing yourself to

1442

01:04:45,910 --> 01:04:43,440

when you say that you're slothful

1443

01:04:51,829 --> 01:04:45,920

gee i compare i compare myself to who i

1444

01:05:04,069 --> 01:04:53,109

anyway

1445

01:05:10,630 --> 01:05:07,109

i think i'm decently good at explaining

1446

01:05:10,640 --> 01:05:13,670

um

1447

01:05:18,069 --> 01:05:17,029

often that involves thinking about them

1448

01:05:20,630 --> 01:05:18,079

i mean

1449

01:05:24,710 --> 01:05:20,640

explaining is not just

1450

01:05:30,309 --> 01:05:26,789

reproducing what you've heard somewhere

1451

01:05:33,910 --> 01:05:30,319

else i mean it's it's first of all

1452

01:05:35,430 --> 01:05:33,920

being creative about these things

1453

01:05:37,029 --> 01:05:35,440

um

1454

01:05:41,190 --> 01:05:37,039

but you know

1455

01:05:44,789 --> 01:05:42,870

ask the students

1456

01:05:46,549 --> 01:05:44,799

ask the people who listen to me in

1457

01:05:48,829 --> 01:05:46,559

lectures

1458

01:05:53,589 --> 01:05:48,839

when i give research

1459

01:05:58,789 --> 01:05:55,430

it's very hard to

1460

01:06:03,430 --> 01:06:00,630

you know

1461

01:06:05,589 --> 01:06:03,440

there's a famous uh story about einstein

1462

01:06:08,390 --> 01:06:05,599

that

1463

01:06:10,789 --> 01:06:08,400

somebody complained to einstein about

1464

01:06:12,950 --> 01:06:10,799

his problems with math

1465

01:06:15,349 --> 01:06:12,960

and their reference was to high school

1466

01:06:16,630 --> 01:06:15,359

math like i never got high school math

1467

01:06:19,349 --> 01:06:16,640

and

1468

01:06:23,109 --> 01:06:19,359

einstein said let me assure you that my

1469

01:06:24,789 --> 01:06:23,990

uh

1470

01:06:25,990 --> 01:06:24,799

so

1471

01:06:28,309 --> 01:06:26,000

uh

1472

01:06:29,589 --> 01:06:28,319

sort of meaning what what did he mean by

1473

01:06:31,589 --> 01:06:29,599

that

1474

01:06:36,390 --> 01:06:31,599

you know i

1475

01:06:42,789 --> 01:06:39,589

all his life struggling with mathematics

1476

01:06:47,349 --> 01:06:42,799

not just high school time

1477

01:06:49,190 --> 01:06:47,359

okay so in a similar way uh gee i'm

1478

01:06:51,430 --> 01:06:49,200

sorry i mean now it might sound like i

1479

01:06:52,470 --> 01:06:51,440

need some analogy which i do i'm not

1480

01:06:55,589 --> 01:06:52,480

making

1481

01:06:57,029 --> 01:06:55,599

i understand trust me uh but but still

1482

01:07:01,109 --> 01:06:57,039

um

1483

01:07:03,510 --> 01:07:01,119

you know i like to implement

1484

01:07:06,069 --> 01:07:03,520

i like to compute things

1485

01:07:08,470 --> 01:07:06,079

implement them on the computer

1486

01:07:12,230 --> 01:07:08,480

which means that i spend a lot of time

1487

01:07:15,109 --> 01:07:12,240

programming the concepts i work on

1488

01:07:18,309 --> 01:07:15,119

turning them into running programs

1489

01:07:20,069 --> 01:07:18,319

you could say it's my strength but when

1490

01:07:22,230 --> 01:07:20,079

i look at it

1491

01:07:24,470 --> 01:07:22,240

all i see is that i'm struggling and

1492

01:07:26,710 --> 01:07:24,480

struggling and struggling and failing

1493

01:07:28,470 --> 01:07:26,720

and here and then here and there there

1494

01:07:30,549 --> 01:07:28,480

is a minor success

1495

01:07:32,549 --> 01:07:30,559

which gets superseded a little bit later

1496

01:07:33,349 --> 01:07:32,559

by somebody else

1497

01:07:34,710 --> 01:07:33,359

so

1498

01:07:37,349 --> 01:07:34,720

um

1499

01:07:40,069 --> 01:07:37,359

yeah maybe one of my strengths is the

1500

01:07:44,789 --> 01:07:40,079

ability to implement things

1501

01:07:49,510 --> 01:07:47,109

you know turn mathematical concepts into

1502

01:07:50,630 --> 01:07:49,520

running programs

1503

01:07:52,789 --> 01:07:50,640

uh

1504

01:07:56,309 --> 01:07:52,799

but it's also one of the things that

1505

01:07:58,630 --> 01:07:56,319

that keeps me depressed uh was so much

1506

01:08:00,309 --> 01:07:58,640

of my time

1507

01:08:02,950 --> 01:08:00,319

some people who are watching this they

1508

01:08:04,630 --> 01:08:02,960

may be discouraged because they were

1509

01:08:07,670 --> 01:08:04,640

they weren't particularly great at high

1510

01:08:09,270 --> 01:08:07,680

school mathematics or some people may

1511

01:08:11,510 --> 01:08:09,280

have struggled during their undergrad

1512

01:08:12,789 --> 01:08:11,520

what advice do you have for those people

1513

01:08:15,589 --> 01:08:12,799

if they want to continue to learn

1514

01:08:17,110 --> 01:08:15,599

mathematics or physics at a

1515

01:08:19,430 --> 01:08:17,120

graduate perhaps even larger than

1516

01:08:21,189 --> 01:08:19,440

graduate phd level

1517

01:08:23,430 --> 01:08:21,199

do they just continue

1518

01:08:25,669 --> 01:08:23,440

plugging away and not feel discouraged

1519

01:08:28,709 --> 01:08:25,679

because they feel like in imbecile on a

1520

01:08:35,110 --> 01:08:31,829

what advice do you have for them

1521

01:08:37,030 --> 01:08:35,120

there is chug along

1522

01:08:39,269 --> 01:08:37,040

and there is realize when it's not

1523

01:08:41,269 --> 01:08:39,279

working

1524

01:08:43,430 --> 01:08:41,279

and i hate to tell you that i don't know

1525

01:08:45,189 --> 01:08:43,440

i mean i can't give you a

1526

01:08:58,470 --> 01:08:45,199

a

1527

01:09:02,550 --> 01:08:58,480

struggle until

1528

01:09:04,470 --> 01:09:02,560

they succeed sometimes some people don't

1529

01:09:08,630 --> 01:09:04,480

uh or they struggle and struggle and

1530

01:09:08,640 --> 01:09:13,669

you get

1531

01:09:13,679 --> 01:09:18,870

feedback

1532

01:09:22,070 --> 01:09:19,829

i mean

1533

01:09:24,070 --> 01:09:22,080

some people depend on daily feedback

1534

01:09:26,789 --> 01:09:24,080

some people can leave with a feedback

1535

01:09:32,470 --> 01:09:26,799

with a bit of feedback once a year

1536

01:09:32,480 --> 01:09:36,550

a clear answer

1537

01:09:41,030 --> 01:09:38,789

what did you learn from ed whitton with

1538

01:09:42,630 --> 01:09:41,040

respect to mathematical techniques or

1539

01:09:43,749 --> 01:09:42,640

meta mathematical so how you should

1540

01:09:46,630 --> 01:09:43,759

think about

1541

01:09:46,640 --> 01:09:53,749

or physics

1542

01:09:57,030 --> 01:09:56,149

well i learned specific mathematics from

1543

01:09:59,510 --> 01:09:57,040

him

1544

01:10:02,630 --> 01:09:59,520

right so you know i learned like many

1545

01:10:04,630 --> 01:10:02,640

other people i learned this formula

1546

01:10:06,870 --> 01:10:04,640

from him

1547

01:10:09,910 --> 01:10:06,880

right and how to read it and how to use

1548

01:10:11,910 --> 01:10:09,920

use it interpret it work with it right

1549

01:10:15,030 --> 01:10:11,920

do things with it

1550

01:10:16,390 --> 01:10:15,040

but i learned many other specific things

1551  
01:10:18,950 --> 01:10:16,400  
with him

1552  
01:10:26,550 --> 01:10:22,550  
um

1553  
01:10:31,110 --> 01:10:26,560  
mean like

1554  
01:10:36,390 --> 01:10:32,470  
researcher

1555  
01:10:39,590 --> 01:10:36,400  
but he's also a great expositor

1556  
01:10:39,600 --> 01:10:45,030  
when you come to his lectures

1557  
01:10:47,830 --> 01:10:46,870  
he is

1558  
01:10:50,229 --> 01:10:47,840  
uh

1559  
01:10:52,709 --> 01:10:50,239  
able to make

1560  
01:10:54,870 --> 01:10:52,719  
even very complicated things appear

1561  
01:10:56,550 --> 01:10:54,880  
simple

1562  
01:10:59,110 --> 01:10:56,560  
uh

1563  
01:11:01,990 --> 01:10:59,120

the problem is that often you will not

1564

01:11:05,350 --> 01:11:02,000

see that because he's turning the hyper

1565

01:11:08,310 --> 01:11:05,360

complicated into merely complicated

1566

01:11:10,390 --> 01:11:08,320

uh so so so so so you don't

1567

01:11:14,550 --> 01:11:10,400

automatically realize

1568

01:11:18,790 --> 01:11:14,560

uh what a great uh exposition

1569

01:11:23,270 --> 01:11:21,189

and i i

1570

01:11:25,590 --> 01:11:23,280

think i learned well i don't know if i

1571

01:11:29,910 --> 01:11:25,600

learned that from him

1572

01:11:32,229 --> 01:11:29,920

but i strive to learn that from him

1573

01:11:34,950 --> 01:11:32,239

um

1574

01:11:37,270 --> 01:11:34,960

and then in other ways i

1575

01:11:39,030 --> 01:11:37,280

there are senses in which i didn't learn

1576

01:11:41,990 --> 01:11:39,040

anything from him

1577

01:11:44,709 --> 01:11:42,000

namely uh he is

1578

01:11:46,870 --> 01:11:44,719

so much more talented

1579

01:11:49,110 --> 01:11:46,880

there's just no way of no other way of

1580

01:11:52,830 --> 01:11:49,120

saying it the guy is smart

1581

01:11:58,550 --> 01:11:52,840

the guy is extremely productive

1582

01:11:59,990 --> 01:11:58,560

uh if you try to imitate his

1583

01:12:01,350 --> 01:12:00,000

brilliance

1584

01:12:03,189 --> 01:12:01,360

you'll fail

1585

01:12:05,910 --> 01:12:03,199

at least i failed

1586

01:12:09,590 --> 01:12:05,920

uh if you try to imitate his

1587

01:12:10,470 --> 01:12:09,600

productivity you'll just be disappointed

1588

01:12:11,990 --> 01:12:10,480

so

1589

01:12:14,790 --> 01:12:12,000

um

1590

01:12:16,310 --> 01:12:14,800

in some ways i haven't learned there are

1591

01:12:19,430 --> 01:12:16,320

certain things i haven't learned from

1592

01:12:21,350 --> 01:12:19,440

him and i just simply couldn't

1593

01:12:23,270 --> 01:12:21,360

do you mind describing your relationship

1594

01:12:25,270 --> 01:12:23,280

with eric weinstein when i was speaking

1595

01:12:28,310 --> 01:12:25,280

to eric he said that you acted as a de

1596

01:12:31,590 --> 01:12:28,320

facto supervisor to him

1597

01:12:33,510 --> 01:12:31,600

because raul bot wasn't particularly

1598

01:12:36,630 --> 01:12:33,520

although it was officially his

1599

01:12:38,470 --> 01:12:36,640

supervisor he didn't act as the

1600

01:12:40,390 --> 01:12:38,480

supervisor for whatever reason it was a

1601  
01:12:41,110 --> 01:12:40,400  
strange relationship i don't understand

1602  
01:12:42,870 --> 01:12:41,120  
it

1603  
01:12:44,630 --> 01:12:42,880  
i'm curious what do you think he means

1604  
01:12:46,550 --> 01:12:44,640  
when he says that you acted as the

1605  
01:12:48,950 --> 01:12:46,560  
supervisor you gave him advice or i

1606  
01:12:59,990 --> 01:12:48,960  
don't think it's correct it's more like

1607  
01:13:00,000 --> 01:13:03,430  
so eric

1608  
01:13:08,630 --> 01:13:06,390  
eric was very unbalanced

1609  
01:13:11,669 --> 01:13:08,640  
and he still is unbalanced and i don't

1610  
01:13:13,669 --> 01:13:11,679  
mean emotionally unbalanced i mean

1611  
01:13:16,550 --> 01:13:13,679  
uh he has

1612  
01:13:19,990 --> 01:13:16,560  
great talents

1613  
01:13:21,430 --> 01:13:20,000

in certain directions

1614

01:13:23,030 --> 01:13:21,440

and

1615

01:13:24,630 --> 01:13:23,040

fear

1616

01:13:26,470 --> 01:13:24,640

of others

1617

01:13:29,350 --> 01:13:26,480

and there are certain

1618

01:13:33,910 --> 01:13:29,360

things that one has to do certain type

1619

01:13:38,790 --> 01:13:33,920

of computation a certain type of writing

1620

01:13:40,550 --> 01:13:38,800

basically he has fear of turning his um

1621

01:13:44,229 --> 01:13:40,560

his

1622

01:13:48,070 --> 01:13:46,370

uh so um

1623

01:13:49,669 --> 01:13:48,080

[Music]

1624

01:13:52,070 --> 01:13:49,679

uh

1625

01:13:55,350 --> 01:13:52,080

and and that's

1626

01:13:56,470 --> 01:13:55,360

part of the reason why he had difficulty

1627

01:13:59,590 --> 01:13:56,480

uh

1628

01:14:01,350 --> 01:13:59,600

with raul balt and with um

1629

01:14:02,709 --> 01:14:01,360

basically with the normal system in

1630

01:14:07,669 --> 01:14:02,719

harvard

1631

01:14:15,750 --> 01:14:11,030

my role was to help him pick something

1632

01:14:19,350 --> 01:14:17,830

big theories

1633

01:14:25,270 --> 01:14:19,360

and

1634

01:14:31,189 --> 01:14:25,280

thesis

1635

01:14:35,669 --> 01:14:32,709

yeah i also helped him with some

1636

01:14:37,750 --> 01:14:35,679

computations you know i you know

1637

01:14:41,510 --> 01:14:37,760

at the end of the day there are some

1638

01:14:43,669 --> 01:14:41,520

like so so he's come he's

1639

01:14:45,750 --> 01:14:43,679

you know big theories

1640

01:14:47,990 --> 01:14:45,760

lead to something very concrete and

1641

01:14:50,470 --> 01:14:48,000

specific which was a tiny part of the

1642

01:14:53,350 --> 01:14:50,480

big theories but we extracted that tiny

1643

01:14:55,750 --> 01:14:53,360

part and made it uh more concrete and at

1644

01:14:58,870 --> 01:14:55,760

the end it became a question you know

1645

01:15:00,310 --> 01:14:58,880

some big matrix 500 by 500 or whatever

1646

01:15:03,510 --> 01:15:00,320

it was

1647

01:15:06,870 --> 01:15:03,520

is it positive definite or not

1648

01:15:09,030 --> 01:15:06,880

and i helped him uh i helped him

1649

01:15:11,430 --> 01:15:09,040

decide that

1650

01:15:13,189 --> 01:15:11,440

and that was decided by compute by a

1651  
01:15:15,350 --> 01:15:13,199  
computer like you ended up programming

1652  
01:15:16,310 --> 01:15:15,360  
it that one that one was decided by

1653  
01:15:17,910 --> 01:15:16,320  
computer

1654  
01:15:19,990 --> 01:15:17,920  
so we just

1655  
01:15:21,030 --> 01:15:20,000  
uh but

1656  
01:15:26,709 --> 01:15:21,040  
but

1657  
01:15:29,110 --> 01:15:26,719  
have never done on on his own

1658  
01:15:30,790 --> 01:15:29,120  
because

1659  
01:15:32,390 --> 01:15:30,800  
he has this

1660  
01:15:34,070 --> 01:15:32,400  
fear of

1661  
01:15:35,910 --> 01:15:34,080  
uh

1662  
01:15:37,189 --> 01:15:35,920  
in a way it's a fear of testing your

1663  
01:15:39,510 --> 01:15:37,199

theories

1664

01:15:42,790 --> 01:15:39,520

because they might fail but in another

1665

01:15:45,590 --> 01:15:42,800

way it's just inability he never

1666

01:15:47,669 --> 01:15:45,600

learned how to do it he never got good

1667

01:15:52,310 --> 01:15:47,679

at um

1668

01:15:54,870 --> 01:15:52,320

turning the very abstract into concrete

1669

01:15:54,880 --> 01:15:58,950

so yes so that was my role

1670

01:16:04,070 --> 01:16:01,669

have you read his recent geometric unity

1671

01:16:06,390 --> 01:16:04,080

papers or heard about geometric unity at

1672

01:16:08,470 --> 01:16:06,400

all i've heard a tiny bit about it i

1673

01:16:09,910 --> 01:16:08,480

have not read it i'm not in the position

1674

01:16:12,310 --> 01:16:09,920

to comment

1675

01:16:14,149 --> 01:16:12,320

you talked about it's difficult to make

1676

01:16:16,550 --> 01:16:14,159

a concrete or take something concrete

1677

01:16:18,310 --> 01:16:16,560

from a theory at least in his case

1678

01:16:20,070 --> 01:16:18,320

do you mind giving an example of his

1679

01:16:30,630 --> 01:16:20,080

strengths or some or an example of a

1680

01:16:44,709 --> 01:16:31,830

he

1681

01:16:44,719 --> 01:16:48,070

uh

1682

01:16:52,390 --> 01:16:49,350

how they

1683

01:16:54,390 --> 01:16:52,400

interact with each other

1684

01:16:55,750 --> 01:16:54,400

uh so

1685

01:16:57,750 --> 01:16:55,760

uh

1686

01:16:59,030 --> 01:16:57,760

the small groups like the classical

1687

01:17:00,390 --> 01:16:59,040

groups or what do you mean when you say

1688

01:17:04,149 --> 01:17:00,400

the smoke

1689

01:17:05,189 --> 01:17:04,159

okay what i mean by the small is um

1690

01:17:06,390 --> 01:17:05,199

so you know

1691

01:17:09,430 --> 01:17:06,400

uh

1692

01:17:11,350 --> 01:17:09,440

there are several families of so-called

1693

01:17:14,149 --> 01:17:11,360

symmetry groups

1694

01:17:16,550 --> 01:17:14,159

okay so there are uh

1695

01:17:19,430 --> 01:17:16,560

uh s-u-n

1696

01:17:21,430 --> 01:17:19,440

and s-uh

1697

01:17:23,830 --> 01:17:21,440

and s-o-n

1698

01:17:26,149 --> 01:17:23,840

and s-p-n

1699

01:17:28,149 --> 01:17:26,159

and then there are a few sporadic ones

1700

01:17:31,830 --> 01:17:28,159

there is uh

1701

01:17:35,350 --> 01:17:31,840

uh g2 and f4

1702

01:17:39,830 --> 01:17:35,360

and e6 and e7

1703

01:17:42,390 --> 01:17:39,840

and e8 and it doesn't go beyond eight

1704

01:17:46,550 --> 01:17:42,400

uh and all of these so these are

1705

01:17:50,470 --> 01:17:48,950

they they have so-called representation

1706

01:17:51,430 --> 01:17:50,480

theory

1707

01:17:52,310 --> 01:17:51,440

so

1708

01:17:55,030 --> 01:17:52,320

uh

1709

01:17:58,709 --> 01:17:55,040

each one of them can be represented can

1710

01:18:00,950 --> 01:17:58,719

be written as a group of matrices can be

1711

01:18:03,430 --> 01:18:00,960

realized within the world of matrices

1712

01:18:05,189 --> 01:18:03,440

but in many ways

1713

01:18:07,189 --> 01:18:05,199

so eric

1714

01:18:09,270 --> 01:18:07,199

uh

1715

01:18:14,870 --> 01:18:09,280

intimately knows

1716

01:18:18,709 --> 01:18:16,390

these groups

1717

01:18:20,870 --> 01:18:18,719

and their representations and how they

1718

01:18:23,430 --> 01:18:20,880

sit inside each other

1719

01:18:25,510 --> 01:18:23,440

for small values of  $n$

1720

01:18:27,590 --> 01:18:25,520

and well for all of those sporadic ones

1721

01:18:29,990 --> 01:18:27,600

which are all small

1722

01:18:32,630 --> 01:18:30,000

and their symmetries and their so-called

1723

01:18:33,990 --> 01:18:32,640

outer symmetries i mean he knows all

1724

01:18:34,870 --> 01:18:34,000

about

1725

01:18:37,189 --> 01:18:34,880

uh

1726

01:18:38,630 --> 01:18:37,199

these things

1727

01:18:41,270 --> 01:18:38,640

now

1728

01:18:42,470 --> 01:18:41,280

this is relevant to physics

1729

01:18:45,590 --> 01:18:42,480

because

1730

01:18:48,630 --> 01:18:45,600

uh you know electro weak theory is

1731

01:18:50,950 --> 01:18:48,640

somehow about su 2

1732

01:18:58,070 --> 01:18:53,990

the grand unified theory so a strong and

1733

01:18:59,270 --> 01:18:58,080

electroweak is somehow about su 3

1734

01:19:00,390 --> 01:18:59,280

or

1735

01:19:03,350 --> 01:19:00,400

so

1736

01:19:05,669 --> 01:19:03,360

uh no no no no no i have it wrong

1737

01:19:08,070 --> 01:19:05,679

sorry electromagnetism is

1738

01:19:10,310 --> 01:19:08,080

well electromagnetism

1739

01:19:11,350 --> 01:19:10,320

is you one and then

1740

01:19:12,390 --> 01:19:11,360

you know i

1741

01:19:17,350 --> 01:19:12,400

i i

1742

01:19:19,910 --> 01:19:17,360

these things for many many years

1743

01:19:22,229 --> 01:19:19,920

so i could be saying things wrong

1744

01:19:24,630 --> 01:19:22,239

but yeah but his strength is that he

1745

01:19:26,950 --> 01:19:24,640

knows these things really really really

1746

01:19:26,960 --> 01:19:29,430

uh

1747

01:19:33,990 --> 01:19:31,750

or one of his strengths is that he knows

1748

01:19:35,270 --> 01:19:34,000

these things really really really well

1749

01:19:37,510 --> 01:19:35,280

earlier when we were talking about

1750

01:19:39,189 --> 01:19:37,520

particle physics well not theory you

1751

01:19:41,590 --> 01:19:39,199

mentioned that for every knot there's a

1752

01:19:44,870 --> 01:19:41,600

corresponding physics story of particles

1753

01:19:46,390 --> 01:19:44,880

dancing and so on is the opposite true

1754

01:19:47,990 --> 01:19:46,400

so does the arrow go in the other

1755

01:19:49,830 --> 01:19:48,000

direction as well

1756

01:19:53,750 --> 01:19:49,840

for every particle interaction is there

1757

01:19:57,669 --> 01:19:55,990

for every particle interaction of a

1758

01:20:00,709 --> 01:19:57,679

specific type

1759

01:20:02,790 --> 01:20:00,719

in three-dimensional space

1760

01:20:05,189 --> 01:20:02,800

yes

1761

01:20:07,669 --> 01:20:05,199

but uh but you have to

1762

01:20:10,470 --> 01:20:07,679

be very specific you have to be you have

1763

01:20:11,910 --> 01:20:10,480

to specialize a great deal

1764

01:20:14,229 --> 01:20:11,920

physics mostly happens in

1765

01:20:15,990 --> 01:20:14,239

four-dimensional space

1766

01:20:18,470 --> 01:20:16,000

if this can be easily explained why is

1767

01:20:20,709 --> 01:20:18,480

it not simple to just extend the three

1768

01:20:21,830 --> 01:20:20,719

dimensions to four dimensions

1769

01:20:25,990 --> 01:20:21,840

and

1770

01:20:28,629 --> 01:20:26,000

vector in we're talking about vector

1771

01:20:31,669 --> 01:20:28,639

spaces it's trivial to go from  $r^3$  to  $r^4$

1772

01:20:33,270 --> 01:20:31,679

the same theorems apply okay so so the

1773

01:20:34,310 --> 01:20:33,280

answer is

1774

01:20:35,910 --> 01:20:34,320

um

1775

01:20:40,390 --> 01:20:35,920

or there's

1776

01:20:41,590 --> 01:20:40,400

first of all certain things do extend

1777

01:20:43,669 --> 01:20:41,600

so

1778

01:20:45,430 --> 01:20:43,679

um

1779

01:20:46,950 --> 01:20:45,440

you know if not

1780

01:20:50,229 --> 01:20:46,960

theory is

1781

01:20:53,590 --> 01:20:50,239

to some extent about dance the dancing

1782

01:20:55,030 --> 01:20:53,600

of points in two-dimensional space

1783

01:20:57,030 --> 01:20:55,040

so

1784

01:20:58,629 --> 01:20:57,040

you know he he

1785

01:21:01,990 --> 01:20:58,639

here is a

1786

01:21:03,510 --> 01:21:02,000

a very rough uh

1787

01:21:07,510 --> 01:21:03,520

uh

1788

01:21:11,669 --> 01:21:07,520

so

1789

01:21:17,510 --> 01:21:12,550

or

1790

01:21:18,390 --> 01:21:17,520

is roughly about

1791

01:21:20,149 --> 01:21:18,400

one

1792

01:21:22,070 --> 01:21:20,159

dimensional

1793

01:21:24,390 --> 01:21:22,080

things

1794

01:21:25,390 --> 01:21:24,400

or curves or whatever

1795

01:21:27,990 --> 01:21:25,400

in

1796

01:21:31,110 --> 01:21:28,000

three-dimensional space

1797

01:21:32,950 --> 01:21:31,120

and as i mentioned before

1798

01:21:34,870 --> 01:21:32,960

it can be

1799

01:21:36,870 --> 01:21:34,880

um

1800

01:21:37,830 --> 01:21:36,880

interpreted

1801  
01:21:39,830 --> 01:21:37,840  
as

1802  
01:21:42,709 --> 01:21:39,840  
points dancing

1803  
01:21:46,229 --> 01:21:42,719  
in two-dimensional place space

1804  
01:21:47,110 --> 01:21:46,239  
so points are zero dimensional

1805  
01:21:48,870 --> 01:21:47,120  
so

1806  
01:21:49,990 --> 01:21:48,880  
uh you can

1807  
01:21:52,470 --> 01:21:50,000  
uh

1808  
01:21:54,629 --> 01:21:52,480  
so you can interpret no theory as zero

1809  
01:21:56,310 --> 01:21:54,639  
dimensional things

1810  
01:21:57,910 --> 01:21:56,320  
right a single point is a zero

1811  
01:22:03,350 --> 01:21:57,920  
dimensional thing

1812  
01:22:04,790 --> 01:22:03,360  
dancing

1813  
01:22:06,149 --> 01:22:04,800

in

1814

01:22:16,310 --> 01:22:06,159

a

1815

01:22:18,470 --> 01:22:16,320

one dimension up

1816

01:22:21,510 --> 01:22:18,480

so you can say

1817

01:22:25,430 --> 01:22:21,520

uh let's uh

1818

01:22:32,550 --> 01:22:28,790

zero dimensional things dancing in  $r^2$

1819

01:22:34,790 --> 01:22:32,560

you can think of one-dimensional

1820

01:22:37,750 --> 01:22:34,800

things

1821

01:22:37,760 --> 01:22:40,149

in

1822

01:22:42,550 --> 01:22:41,189

uh

1823

01:22:57,590 --> 01:22:42,560

r

1824

01:22:59,830 --> 01:22:57,600

sections

1825

01:23:00,750 --> 01:22:59,840

they somehow corresponds

1826

01:23:04,830 --> 01:23:00,760

to

1827

01:23:09,990 --> 01:23:04,840

two-dimensional notes so two-dimensional

1828

01:23:13,350 --> 01:23:11,510

in

1829

01:23:14,629 --> 01:23:13,360

r4

1830

01:23:16,550 --> 01:23:14,639

now you can ask

1831

01:23:19,110 --> 01:23:16,560

now what exactly are what is that

1832

01:23:22,550 --> 01:23:19,120

supposed to be r3 dancing sorry not r4 i

1833

01:23:25,590 --> 01:23:22,560

i wanted to add one this is in r2 adding

1834

01:23:28,149 --> 01:23:25,600

one you get r3

1835

01:23:29,590 --> 01:23:28,159

sorry so one dimensional thing dancing

1836

01:23:31,270 --> 01:23:29,600

in r3

1837

01:23:34,470 --> 01:23:31,280

now you can ask yourself what are one

1838

01:23:36,790 --> 01:23:34,480

dimensional things dancing in  $r^3$  and

1839

01:23:39,030 --> 01:23:36,800

fortunately i'm ready for that

1840

01:23:41,189 --> 01:23:39,040

so here are here is a one dimensional

1841

01:23:44,790 --> 01:23:41,199

thing

1842

01:23:48,149 --> 01:23:45,910

and

1843

01:23:50,149 --> 01:23:48,159

uh right this is a loop it's a

1844

01:23:52,229 --> 01:23:50,159

one-dimensional thing that's another one

1845

01:23:54,470 --> 01:23:52,239

it's a loop it's a one-dimensional thing

1846

01:23:56,790 --> 01:23:54,480

and they can dance around they can fly

1847

01:24:00,229 --> 01:23:56,800

in  $r^3$  and they can fly in interesting

1848

01:24:03,189 --> 01:24:00,239

ways that don't exist one dimension less

1849

01:24:04,310 --> 01:24:03,199

namely they can fly through each other

1850

01:24:05,189 --> 01:24:04,320

okay

1851

01:24:08,390 --> 01:24:05,199

so

1852

01:24:11,830 --> 01:24:08,400

yes there is a theory of one-dimensional

1853

01:24:14,830 --> 01:24:11,840

things dancing in r3

1854

01:24:18,229 --> 01:24:14,840

and it corresponds to a theory of

1855

01:24:20,149 --> 01:24:18,239

two-dimensional spaces noted inside

1856

01:24:22,629 --> 01:24:20,159

four-dimensional space

1857

01:24:25,030 --> 01:24:22,639

so to some extent

1858

01:24:28,070 --> 01:24:25,040

the answer to your question is yes there

1859

01:24:31,350 --> 01:24:28,080

is higher there are higher dimensional

1860

01:24:33,189 --> 01:24:31,360

analogs of not theory

1861

01:24:33,990 --> 01:24:33,199

it turns out

1862

01:24:34,950 --> 01:24:34,000

that

1863

01:24:38,149 --> 01:24:34,960

uh

1864

01:24:42,229 --> 01:24:38,159

some features are different

1865

01:24:45,430 --> 01:24:42,239

it turns out that in some ways uh

1866

01:24:48,310 --> 01:24:45,440

and they're actually qualitatively

1867

01:24:52,470 --> 01:24:48,320

sort of the theory of not in one them so

1868

01:24:54,950 --> 01:24:52,480

so you know unlike um vector spaces

1869

01:24:57,110 --> 01:24:54,960

so vector spaces you kind of once you

1870

01:24:59,510 --> 01:24:57,120

learn

1871

01:25:03,990 --> 01:24:59,520

$r^3$

1872

01:25:04,950 --> 01:25:04,000

$r^4$  you've learned  $r$  to the 50.

1873

01:25:07,990 --> 01:25:04,960

okay

1874

01:25:10,310 --> 01:25:08,000

but but but here there are qualitative

1875

01:25:11,350 --> 01:25:10,320

differences

1876

01:25:12,870 --> 01:25:11,360

so

1877

01:25:13,830 --> 01:25:12,880

uh

1878

01:25:19,510 --> 01:25:13,840

so

1879

01:25:22,310 --> 01:25:19,520

translate to things here and vice versa

1880

01:25:23,750 --> 01:25:22,320

but not everything

1881

01:25:26,229 --> 01:25:23,760

so

1882

01:25:30,149 --> 01:25:26,239

myself i've spent most of my time

1883

01:25:33,510 --> 01:25:31,590

okay

1884

01:25:35,430 --> 01:25:33,520

but then there is higher there is even

1885

01:25:38,550 --> 01:25:35,440

higher stuff

1886

01:25:42,790 --> 01:25:41,189

by the way so you know

1887

01:25:46,470 --> 01:25:42,800

um

1888

01:25:49,590 --> 01:25:48,149

uh

1889

01:25:52,390 --> 01:25:49,600

when you take

1890

01:25:55,270 --> 01:25:52,400

a first class in linear algebra and

1891

01:25:57,990 --> 01:25:55,280

maybe also a second class in linear

1892

01:25:59,590 --> 01:25:58,000

algebra you get this impression

1893

01:26:01,910 --> 01:25:59,600

that

1894

01:26:03,430 --> 01:26:01,920

uh everything is the same in all

1895

01:26:04,310 --> 01:26:03,440

dimensions

1896

01:26:06,550 --> 01:26:04,320

yep

1897

01:26:08,709 --> 01:26:06,560

but that's not true

1898

01:26:09,910 --> 01:26:08,719

even in linear algebra even in linear

1899

01:26:10,709 --> 01:26:09,920

algebra

1900

01:26:13,030 --> 01:26:10,719

so

1901

01:26:15,270 --> 01:26:13,040

well not quite linear algebra but in

1902

01:26:18,070 --> 01:26:15,280

algebra

1903

01:26:21,830 --> 01:26:18,080

okay so you know there is something

1904

01:26:23,189 --> 01:26:21,840

called uh the real numbers

1905

01:26:25,669 --> 01:26:23,199

then you can

1906

01:26:30,709 --> 01:26:25,679

add i

1907

01:26:31,910 --> 01:26:30,719

and you get the complex numbers

1908

01:26:33,750 --> 01:26:31,920

and then

1909

01:26:37,910 --> 01:26:33,760

uh you can say

1910

01:26:39,110 --> 01:26:37,920

let's add uh j and k as well

1911

01:26:43,669 --> 01:26:39,120

and you get

1912

01:26:45,990 --> 01:26:43,679

uh the so-called uh quaternions

1913

01:26:48,229 --> 01:26:46,000

but the quaternions are different than

1914

01:26:49,590 --> 01:26:48,239

the complex numbers in that this is a

1915

01:26:50,470 --> 01:26:49,600

commutative

1916

01:26:55,430 --> 01:26:50,480

ring

1917

01:26:57,910 --> 01:26:55,440

and then you can add  $g$  i forgot what's

1918

01:26:59,830 --> 01:26:57,920

the standard name for what you add so  $i$

1919

01:27:00,709 --> 01:26:59,840

don't know add

1920

01:27:05,430 --> 01:27:00,719

in

1921

01:27:08,229 --> 01:27:05,440

i forgot the name and and you get

1922

01:27:11,669 --> 01:27:08,239

octaniums and the octaniums are no

1923

01:27:14,709 --> 01:27:11,679

longer even associative

1924

01:27:17,510 --> 01:27:14,719

so it's still sort of a ring

1925

01:27:19,830 --> 01:27:17,520

namely it has a multiplication but it's

1926

01:27:22,070 --> 01:27:19,840

not even associative and then the

1927

01:27:26,070 --> 01:27:22,080

process ends there is just nothing

1928

01:27:27,510 --> 01:27:26,080

beyond that you can't continue

1929

01:27:28,629 --> 01:27:27,520

uh so

1930

01:27:31,510 --> 01:27:28,639

uh

1931

01:27:33,510 --> 01:27:31,520

so even in linear algebra so that's not

1932

01:27:36,310 --> 01:27:33,520

quite well

1933

01:27:38,950 --> 01:27:36,320

i don't know even in basic algebra not

1934

01:27:41,270 --> 01:27:38,960

all dimensions are the same 1 is not the

1935

01:27:44,149 --> 01:27:41,280

same as 2 is not the same as 4 is not

1936

01:27:47,270 --> 01:27:44,159

the same as 8 and not the same as 16

1937

01:27:48,470 --> 01:27:47,280

where things no longer exist

1938

01:27:53,240 --> 01:27:48,480

so

1939

01:27:57,430 --> 01:27:54,629

[Music]

1940

01:27:59,110 --> 01:27:57,440

things are independent of the dimension

1941

01:28:01,270 --> 01:27:59,120

it's only they're only independent of

1942

01:28:01,990 --> 01:28:01,280

the dimension in the first two years of

1943

01:28:04,629 --> 01:28:02,000

uh

1944

01:28:07,189 --> 01:28:04,639

of of undergrad

1945

01:28:09,430 --> 01:28:07,199

now in this example we're going to

1946

01:28:11,750 --> 01:28:09,440

different spaces by adding one

1947

01:28:14,229 --> 01:28:11,760

or by adding whatever extra

1948

01:28:17,030 --> 01:28:14,239

variables there are there in the

1949

01:28:18,550 --> 01:28:17,040

previous example we're extending  $r = 4$  to

1950

01:28:22,310 --> 01:28:18,560

$r = 5$  or

1951

01:28:25,189 --> 01:28:22,320

$r$  to  $n$  plus  $m$

1952

01:28:27,350 --> 01:28:25,199

so we're in the same space in a sense

1953

01:28:30,149 --> 01:28:27,360

except adding an extra dimension so

1954

01:28:31,669 --> 01:28:30,159

what's an example that holds for  $r_3$

1955

01:28:33,189 --> 01:28:31,679

or actually sorry let's make this even

1956

01:28:36,870 --> 01:28:33,199

simpler what's an example that holds for

1957

01:28:39,510 --> 01:28:36,880

$r_2$  but doesn't hold for  $r_3$

1958

01:28:41,590 --> 01:28:39,520

or you can say  $r_3$  to  $r_4$  like what's an

1959

01:28:43,830 --> 01:28:41,600

example of a quantity that drastically

1960

01:28:45,030 --> 01:28:43,840

changes as soon as you go to  $r_4$

1961

01:28:47,590 --> 01:28:45,040

and becomes

1962

01:28:49,750 --> 01:28:47,600

extremely complicated but in  $r_3$  it's

1963

01:28:52,790 --> 01:28:49,760

trivial

1964

01:28:56,229 --> 01:28:52,800

the motion of points

1965

01:28:56,950 --> 01:28:56,239

is fundamentally different

1966

01:29:01,110 --> 01:28:56,960

in

1967

01:29:03,030 --> 01:29:01,120

dimensions

1968

01:29:04,070 --> 01:29:03,040

so let me explain

1969

01:29:05,510 --> 01:29:04,080

so

1970

01:29:08,709 --> 01:29:05,520

uh

1971

01:29:09,669 --> 01:29:08,719

right suppose you have two points  $a$  and

1972

01:29:12,149 --> 01:29:09,679

$b$

1973

01:29:14,550 --> 01:29:12,159

in two dimensions

1974

01:29:17,110 --> 01:29:14,560

and you want them to trade places by

1975

01:29:22,070 --> 01:29:19,510

okay there are two basic ways they can

1976

01:29:23,110 --> 01:29:22,080

do it they can trade place

1977

01:29:27,669 --> 01:29:23,120

by

1978

01:29:28,550 --> 01:29:27,679

uh b going above a

1979

01:29:31,110 --> 01:29:28,560

or

1980

01:29:33,910 --> 01:29:31,120

they can trade places

1981

01:29:36,790 --> 01:29:33,920

uh in some sort sort of the opposite way

1982

01:29:39,430 --> 01:29:36,800

by a going above b so a will go to here

1983

01:29:40,310 --> 01:29:39,440

and b will go sorry a will go

1984

01:30:04,390 --> 01:29:40,320

a

1985

01:30:08,790 --> 01:30:04,400

continuously deform

1986

01:30:12,790 --> 01:30:08,800

this way of moving to that way of moving

1987

01:30:15,990 --> 01:30:12,800

but in  $r_3$  that's not

1988

01:30:19,270 --> 01:30:16,000

true anymore so in r3

1989

01:30:22,550 --> 01:30:19,280

points can trade places

1990

01:30:23,430 --> 01:30:22,560

in only one way

1991

01:30:27,669 --> 01:30:23,440

so

1992

01:30:28,470 --> 01:30:27,679

uh let me uh find two points for you

1993

01:30:31,910 --> 01:30:28,480

so

1994

01:30:32,870 --> 01:30:31,920

uh i suppose

1995

01:30:34,550 --> 01:30:32,880

uh

1996

01:30:39,669 --> 01:30:34,560

well they're not points but they're

1997

01:30:41,030 --> 01:30:39,679

close to points so here is uh red and

1998

01:30:44,790 --> 01:30:41,040

blue

1999

01:30:46,149 --> 01:30:44,800

so in r3 they can trade places going

2000

01:30:49,910 --> 01:30:46,159

this way

2001  
01:30:52,790 --> 01:30:49,920  
or they can trade places going that way

2002  
01:30:54,950 --> 01:30:52,800  
but there are many other ways they can

2003  
01:30:57,350 --> 01:30:54,960  
trade places they can trade places by

2004  
01:30:59,590 --> 01:30:57,360  
going that way or

2005  
01:31:00,709 --> 01:30:59,600  
that way

2006  
01:31:02,870 --> 01:31:00,719  
and

2007  
01:31:05,270 --> 01:31:02,880  
um

2008  
01:31:08,070 --> 01:31:05,280  
in a sense all of these

2009  
01:31:10,629 --> 01:31:08,080  
trading places ways

2010  
01:31:12,070 --> 01:31:10,639  
are equivalent to each other

2011  
01:31:15,030 --> 01:31:12,080  
because

2012  
01:31:19,189 --> 01:31:15,040  
if you trade places

2013  
01:31:23,110 --> 01:31:19,199

wait if the two points trade places

2014

01:31:24,709 --> 01:31:23,120

they span a circle

2015

01:31:29,110 --> 01:31:24,719

right so

2016

01:31:31,189 --> 01:31:29,120

know they

2017

01:31:33,270 --> 01:31:31,199

spun a circle by

2018

01:31:36,310 --> 01:31:33,280

uh i wish i had a third hand maybe i

2019

01:31:39,830 --> 01:31:36,320

removed my sure sure sure okay they go

2020

01:31:43,430 --> 01:31:39,840

like that okay that spawns a circle and

2021

01:31:45,189 --> 01:31:43,440

the other way of spawning a circle is by

2022

01:31:47,830 --> 01:31:45,199

going the other way

2023

01:31:48,950 --> 01:31:47,840

around the same d around the same sorry

2024

01:31:56,550 --> 01:31:48,960

circle

2025

01:31:59,350 --> 01:31:56,560

and that homotops that deforms

2026  
01:32:03,910 --> 01:31:59,360  
one way of trading places to the other

2027  
01:32:07,430 --> 01:32:03,920  
way of trading places so in r3

2028  
01:32:09,030 --> 01:32:07,440  
so in r2 there are two

2029  
01:32:10,709 --> 01:32:09,040  
distinct

2030  
01:32:14,149 --> 01:32:10,719  
sorry this

2031  
01:32:15,910 --> 01:32:14,159  
can spell there are two

2032  
01:32:18,709 --> 01:32:15,920  
uh

2033  
01:32:20,229 --> 01:32:18,719  
distinct

2034  
01:32:21,270 --> 01:32:20,239  
ways

2035  
01:32:22,310 --> 01:32:21,280  
of

2036  
01:32:24,149 --> 01:32:22,320  
uh

2037  
01:32:27,030 --> 01:32:24,159  
trading

2038  
01:32:29,189 --> 01:32:27,040

uh places

2039

01:32:31,270 --> 01:32:29,199

and in fact two are easy they're

2040

01:32:32,550 --> 01:32:31,280

actually a little bit more but anyway in

2041

01:32:33,950 --> 01:32:32,560

r3

2042

01:32:37,750 --> 01:32:33,960

so if you're talking about

2043

01:32:41,189 --> 01:32:39,350

and you have

2044

01:32:42,470 --> 01:32:41,199

two points in the three-dimensional

2045

01:32:43,830 --> 01:32:42,480

space there is

2046

01:32:45,030 --> 01:32:43,840

only

2047

01:32:46,229 --> 01:32:45,040

one

2048

01:32:51,430 --> 01:32:46,239

way

2049

01:32:55,270 --> 01:32:51,440

different let me say differently

2050

01:32:56,629 --> 01:32:55,280

uh all ways of trading places all

2051  
01:32:57,910 --> 01:32:56,639

ways

2052  
01:32:59,510 --> 01:32:57,920

of

2053  
01:33:03,189 --> 01:32:59,520

trading

2054  
01:33:07,430 --> 01:33:04,229

are

2055  
01:33:09,830 --> 01:33:07,440  
equivalent and again the basic the basic

2056  
01:33:12,470 --> 01:33:09,840  
point is that a way of trading places is

2057  
01:33:14,790 --> 01:33:12,480  
a circle right right one point goes

2058  
01:33:18,310 --> 01:33:14,800  
along one arc and the other point goes

2059  
01:33:19,750 --> 01:33:18,320  
about a guy over the other arc and you

2060  
01:33:22,790 --> 01:33:19,760  
can

2061  
01:33:24,470 --> 01:33:22,800  
switch from one place of trading place

2062  
01:33:26,470 --> 01:33:24,480  
one way of trading places to the other

2063  
01:33:29,510 --> 01:33:26,480

by flipping the circle you can't do it

2064

01:33:31,030 --> 01:33:29,520

if you're only in the plane

2065

01:33:34,830 --> 01:33:31,040

um

2066

01:33:39,110 --> 01:33:34,840

since trading places is actually

2067

01:33:40,950 --> 01:33:39,120

fundamental it makes uh

2068

01:33:42,229 --> 01:33:40,960

but by the way it's also fundamental in

2069

01:33:44,470 --> 01:33:42,239

physics

2070

01:33:46,629 --> 01:33:44,480

so you know you you you know you you

2071

01:33:48,950 --> 01:33:46,639

might have heard of uh bosons and

2072

01:33:51,270 --> 01:33:48,960

fermions and how they behave

2073

01:33:53,830 --> 01:33:51,280

with respect to trading places and then

2074

01:33:56,390 --> 01:33:53,840

there are any ones that behave yet

2075

01:33:59,430 --> 01:33:56,400

differently uh with respect to trading

2076

01:34:01,669 --> 01:33:59,440

places so basically trading places or

2077

01:34:04,070 --> 01:34:01,679

how things behave under trading places

2078

01:34:05,110 --> 01:34:04,080

is a fundamental

2079

01:34:07,590 --> 01:34:05,120

thing

2080

01:34:10,070 --> 01:34:07,600

and it's different it's it's different

2081

01:34:11,990 --> 01:34:10,080

in two dimensions than in three

2082

01:34:13,830 --> 01:34:12,000

right likewise there are things that are

2083

01:34:14,870 --> 01:34:13,840

different between three dimensions and

2084

01:34:18,149 --> 01:34:14,880

four

2085

01:34:21,510 --> 01:34:18,159

and and so it's actually this kind of

2086

01:34:23,430 --> 01:34:21,520

myth or not myth but this um

2087

01:34:26,790 --> 01:34:23,440

the thing that you learn in first and

2088

01:34:30,070 --> 01:34:26,800

second year that uh rn is the same rn no

2089

01:34:31,669 --> 01:34:30,080

matter what n is is not actually true

2090

01:34:32,950 --> 01:34:31,679

have you heard of the hard problem of

2091

01:34:35,830 --> 01:34:32,960

consciousness

2092

01:34:38,070 --> 01:34:35,840

i have not heard it in this language

2093

01:34:39,990 --> 01:34:38,080

namely no no has nothing to do with

2094

01:34:41,590 --> 01:34:40,000

what was written on the board or maybe

2095

01:34:43,990 --> 01:34:41,600

it does but not as far as i see this is

2096

01:34:47,030 --> 01:34:44,000

sort of a clear philosophical problem

2097

01:34:49,830 --> 01:34:47,040

right but uh with the added prefix the

2098

01:34:52,709 --> 01:34:49,840

high and it's clearly hard

2099

01:34:54,229 --> 01:34:52,719

but but but as a phrase the hard problem

2100

01:34:57,350 --> 01:34:54,239

of consciousness i don't know what

2101  
01:35:02,870 --> 01:34:59,270  
there's only one consciousness that i

2102  
01:35:05,430 --> 01:35:02,880  
need to explain and it's my own

2103  
01:35:07,990 --> 01:35:05,440  
right from my perspective

2104  
01:35:10,390 --> 01:35:08,000  
you're not conscious

2105  
01:35:13,590 --> 01:35:10,400  
right you just react to

2106  
01:35:15,430 --> 01:35:13,600  
to to things that i do you know if i

2107  
01:35:18,470 --> 01:35:15,440  
you know if i tell you

2108  
01:35:20,709 --> 01:35:18,480  
uh you're stupid you get angry at me if

2109  
01:35:22,149 --> 01:35:20,719  
i give you a compliment you get happy

2110  
01:35:24,790 --> 01:35:22,159  
but these are all

2111  
01:35:27,350 --> 01:35:24,800  
i don't see consciousness here

2112  
01:35:29,510 --> 01:35:27,360  
okay i so there's only one consciousness

2113  
01:35:31,109 --> 01:35:29,520

that i have to explain

2114

01:35:35,109 --> 01:35:31,119

and only one person that i have to

2115

01:35:46,950 --> 01:35:36,149

um

2116

01:35:46,960 --> 01:35:50,870

having said that

2117

01:35:50,880 --> 01:35:57,590

um

2118

01:35:57,600 --> 01:36:01,990

yeah i'll keep the rest private

2119

01:36:02,000 --> 01:36:10,790

what keeps you up at night

2120

01:36:10,800 --> 01:36:14,870

different things on different days

2121

01:36:19,030 --> 01:36:17,910

whether she loves me or not

2122

01:36:20,870 --> 01:36:19,040

uh

2123

01:36:22,950 --> 01:36:20,880

whether i can

2124

01:36:26,149 --> 01:36:22,960

complete the computer program or i'm

2125

01:36:29,030 --> 01:36:26,159

writing or not or why is it not written

2126  
01:36:30,870 --> 01:36:29,040  
my classes for tomorrow the theorem i

2127  
01:36:33,590 --> 01:36:30,880  
don't know how to

2128  
01:36:34,950 --> 01:36:33,600  
have no clue how to prove the state of

2129  
01:36:37,270 --> 01:36:34,960  
the world

2130  
01:36:39,510 --> 01:36:37,280  
covered i don't know different things at

2131  
01:36:41,510 --> 01:36:39,520  
different times

2132  
01:36:44,070 --> 01:36:41,520  
is there a through line so let's say one

2133  
01:37:01,189 --> 01:36:44,080  
that you've been thinking about for 15

2134  
01:37:09,189 --> 01:37:04,470  
you know i'm politically aware

2135  
01:37:11,430 --> 01:37:09,199  
and always been have always been so uh

2136  
01:37:13,430 --> 01:37:11,440  
uh

2137  
01:37:15,109 --> 01:37:13,440  
you know how to make the world a better

2138  
01:37:18,470 --> 01:37:15,119

place

2139

01:37:21,030 --> 01:37:18,480

uh but but of course that's a subjective

2140

01:37:23,669 --> 01:37:21,040

thing what what is better

2141

01:37:25,590 --> 01:37:23,679

to me may or may not be the same as what

2142

01:37:27,590 --> 01:37:25,600

is better to you

2143

01:37:29,750 --> 01:37:27,600

so in a way when i'm saying

2144

01:37:31,669 --> 01:37:29,760

uh how to make a better pla the world a

2145

01:37:35,350 --> 01:37:31,679

better place it's more like how to make

2146

01:37:35,360 --> 01:37:44,709

i would how i would like it to be

2147

01:37:48,390 --> 01:37:46,629

yeah so i think about it a lot and

2148

01:37:50,709 --> 01:37:48,400

mostly my conclusion is that there's

2149

01:37:52,790 --> 01:37:50,719

nothing i can do or there is much i can

2150

01:37:57,109 --> 01:37:52,800

do

2151  
01:38:05,510 --> 01:37:58,950  
what direction would you like math

2152  
01:38:12,310 --> 01:38:08,070  
i think i mentioned

2153  
01:38:12,320 --> 01:38:14,870  
um

2154  
01:38:14,880 --> 01:38:21,510  
and i actually uh

2155  
01:38:24,470 --> 01:38:23,350  
so i mean it's not the only thing of

2156  
01:38:26,709 --> 01:38:24,480  
value

2157  
01:38:33,750 --> 01:38:26,719  
in mathematics

2158  
01:38:38,070 --> 01:38:35,109  
regardless of whether they are

2159  
01:38:41,750 --> 01:38:38,080  
computable or not

2160  
01:38:47,669 --> 01:38:44,950  
but those parts of mathematics that can

2161  
01:38:52,070 --> 01:38:47,679  
be computed

2162  
01:38:56,830 --> 01:38:54,629  
and often

2163  
01:38:58,629 --> 01:38:56,840

people

2164

01:39:00,950 --> 01:38:58,639

uh

2165

01:39:02,070 --> 01:39:00,960

just don't care about computations they

2166

01:39:03,750 --> 01:39:02,080

pretend

2167

01:39:05,270 --> 01:39:03,760

that

2168

01:39:07,270 --> 01:39:05,280

well

2169

01:39:09,590 --> 01:39:07,280

they think of computation as something

2170

01:39:13,270 --> 01:39:09,600

as a technical thing to to to live for

2171

01:39:16,870 --> 01:39:13,280

their graduate students

2172

01:39:19,669 --> 01:39:16,880

and i see it as a much more integral

2173

01:39:20,790 --> 01:39:19,679

part of the work

2174

01:39:28,149 --> 01:39:20,800

so

2175

01:39:31,990 --> 01:39:30,629

i i i would make computation a bigger

2176

01:39:33,510 --> 01:39:32,000

part

2177

01:39:35,910 --> 01:39:33,520

computation in the sense of

2178

01:39:38,870 --> 01:39:35,920

implementation on the computer not in

2179

01:39:41,030 --> 01:39:38,880

the sense of writing by hand

2180

01:39:46,149 --> 01:39:41,040

i would make it a much bigger part and i

2181

01:39:51,990 --> 01:39:48,310

and that happens at many levels so when

2182

01:39:54,629 --> 01:39:52,000

you teach a class in linear algebra

2183

01:39:59,350 --> 01:39:54,639

you teach about uh

2184

01:40:01,750 --> 01:40:00,709

well

2185

01:40:03,750 --> 01:40:01,760

uh

2186

01:40:05,750 --> 01:40:03,760

along with it there should be a computer

2187

01:40:07,109 --> 01:40:05,760

program to compute compute the

2188

01:40:08,709 --> 01:40:07,119

determinant

2189

01:40:11,430 --> 01:40:08,719

and should and there should be a

2190

01:40:13,510 --> 01:40:11,440

realization that there are maybe two

2191

01:40:16,470 --> 01:40:13,520

formulas for the determinant and one of

2192

01:40:18,070 --> 01:40:16,480

them is way better than the other

2193

01:40:21,510 --> 01:40:18,080

uh

2194

01:40:23,350 --> 01:40:21,520

if you try to implement it

2195

01:40:25,189 --> 01:40:23,360

uh so

2196

01:40:26,310 --> 01:40:25,199

um

2197

01:40:32,310 --> 01:40:26,320

i would

2198

01:40:35,830 --> 01:40:33,270

um

2199

01:40:38,229 --> 01:40:35,840

yeah maybe that would be the main change

2200

01:40:41,990 --> 01:40:38,239

do you have a philosophy of math so for

2201

01:40:43,750 --> 01:40:42,000

example there's platonism and formalism

2202

01:40:46,390 --> 01:40:43,760

if anything i would be an ultra

2203

01:40:47,350 --> 01:40:46,400

finalitist

2204

01:40:49,990 --> 01:40:47,360

so

2205

01:40:53,669 --> 01:40:50,000

uh

2206

01:40:56,790 --> 01:40:53,679

it's much more graded than that

2207

01:40:57,910 --> 01:40:56,800

so you know there is a hierarchy

2208

01:41:00,310 --> 01:40:57,920

of

2209

01:41:02,350 --> 01:41:00,320

um

2210

01:41:06,709 --> 01:41:02,360

of

2211

01:41:09,189 --> 01:41:06,719

or sizes

2212

01:41:09,990 --> 01:41:09,199

of things in mathematics

2213

01:41:12,550 --> 01:41:10,000

so

2214

01:41:14,629 --> 01:41:12,560

you know people in set theory and logic

2215

01:41:19,990 --> 01:41:14,639

and you know talk about

2216

01:41:20,000 --> 01:41:22,950

and

2217

01:41:26,470 --> 01:41:24,550

then there are

2218

01:41:29,189 --> 01:41:26,480

parts of mathematics that have to do

2219

01:41:31,270 --> 01:41:29,199

with uncountable or

2220

01:41:33,910 --> 01:41:31,280

bigger than uncountable

2221

01:41:36,310 --> 01:41:33,920

and then there are infinite parts

2222

01:41:38,070 --> 01:41:36,320

and then there are just infinite without

2223

01:41:40,310 --> 01:41:38,080

being uncountable right and just

2224

01:41:44,950 --> 01:41:40,320

countable say and then there are parts

2225

01:41:50,870 --> 01:41:47,830

finite but huge

2226

01:41:51,750 --> 01:41:50,880

uh so you know ramsey theory

2227

01:41:57,510 --> 01:41:51,760

uh

2228

01:42:00,229 --> 01:41:57,520

you know you prove that if a graph is

2229

01:42:01,910 --> 01:42:00,239

large enough then it has properties

2230

01:42:04,629 --> 01:42:01,920

certain properties

2231

01:42:06,870 --> 01:42:04,639

but large enough means really really

2232

01:42:09,030 --> 01:42:06,880

really really really really really

2233

01:42:12,830 --> 01:42:09,040

really huge bigger than the number of

2234

01:42:12,840 --> 01:42:17,430

uh and then there are

2235

01:42:21,189 --> 01:42:18,709

uh

2236

01:42:21,990 --> 01:42:21,199

you know parts of mathematics

2237

01:42:32,310 --> 01:42:22,000

uh

2238

01:42:34,070 --> 01:42:32,320

and 10 to the 12 i don't know what a

2239

01:42:36,070 --> 01:42:34,080

computer can do in a fraction of a

2240

01:42:37,990 --> 01:42:36,080

second to what a computer can do in an

2241

01:42:40,470 --> 01:42:38,000

hour

2242

01:42:43,270 --> 01:42:40,480

okay and you know maybe you can go a

2243

01:42:45,430 --> 01:42:43,280

little bit beyond to 10 to the 16 i

2244

01:42:48,470 --> 01:42:45,440

don't know 10 to the 15. i don't know

2245

01:42:53,510 --> 01:42:52,070

so there is this whole grading

2246

01:42:57,510 --> 01:42:53,520

and to me

2247

01:43:01,109 --> 01:42:57,520

the bigger things are

2248

01:43:04,470 --> 01:43:02,709

uh

2249

01:43:07,270 --> 01:43:04,480

and

2250

01:43:09,270 --> 01:43:07,280

because they're farther away from our

2251  
01:43:12,870 --> 01:43:09,280  
everyday experience

2252  
01:43:14,470 --> 01:43:12,880  
so they may have philosophical value and

2253  
01:43:16,629 --> 01:43:14,480  
some of them do

2254  
01:43:17,910 --> 01:43:16,639  
so i don't want to

2255  
01:43:19,030 --> 01:43:17,920  
completely

2256  
01:43:21,430 --> 01:43:19,040  
say

2257  
01:43:22,709 --> 01:43:21,440  
anything about large cardinals is not

2258  
01:43:25,590 --> 01:43:22,719  
interesting

2259  
01:43:28,550 --> 01:43:25,600  
or anything about infinity

2260  
01:43:30,790 --> 01:43:28,560  
is not interesting

2261  
01:43:34,149 --> 01:43:30,800  
but the bar is higher

2262  
01:43:35,430 --> 01:43:34,159  
for something that genuinely use uses

2263  
01:43:37,189 --> 01:43:35,440

infinity

2264

01:43:39,030 --> 01:43:37,199

to be interesting

2265

01:43:41,350 --> 01:43:39,040

the bar is higher

2266

01:43:42,390 --> 01:43:41,360

than if the thing is

2267

01:43:45,270 --> 01:43:42,400

uh

2268

01:43:48,790 --> 01:43:45,280

in this in the range of sizes

2269

01:43:50,550 --> 01:43:48,800

that we can actually hold in our hands

2270

01:43:52,709 --> 01:43:50,560

so that's what i mean by an ultra

2271

01:43:54,070 --> 01:43:52,719

finitist i mean

2272

01:43:56,550 --> 01:43:54,080

sort of the

2273

01:43:58,629 --> 01:43:56,560

or or so this is a form so an ultra

2274

01:44:00,870 --> 01:43:58,639

finalities would say the only numbers

2275

01:44:02,629 --> 01:44:00,880

that exist are the numbers i could count

2276

01:44:04,709 --> 01:44:02,639

to

2277

01:44:07,430 --> 01:44:04,719

and maybe by uh

2278

01:44:10,550 --> 01:44:07,440

extension that my computer could count

2279

01:44:13,990 --> 01:44:10,560

to so maybe my computer can count up to

2280

01:44:16,149 --> 01:44:14,000

this number but 10 to the 100 does not

2281

01:44:19,350 --> 01:44:16,159

exist in some sense because my computer

2282

01:44:22,870 --> 01:44:19,360

will never be able to count there

2283

01:44:23,830 --> 01:44:22,880

okay we'll never be able to get there

2284

01:44:29,830 --> 01:44:23,840

so

2285

01:44:31,910 --> 01:44:29,840

there is value to this one too

2286

01:44:34,390 --> 01:44:31,920

and sometimes there is even value to

2287

01:44:36,709 --> 01:44:34,400

infinity and sometimes there is even

2288

01:44:38,950 --> 01:44:36,719

value to the bigger form of infinity but

2289

01:44:42,550 --> 01:44:38,960

the bar has to be higher

2290

01:44:44,870 --> 01:44:42,560

uh the the the the philosophical value

2291

01:44:47,990 --> 01:44:44,880

bar has to be higher

2292

01:44:49,830 --> 01:44:48,000

the bigger the the size is

2293

01:44:51,590 --> 01:44:49,840

these things are always interesting

2294

01:44:55,030 --> 01:44:51,600

these things are interesting only on

2295

01:44:58,790 --> 01:44:56,790

now i'm not sure do you classify

2296

01:45:00,470 --> 01:44:58,800

yourself as a pure mathematician

2297

01:45:02,709 --> 01:45:00,480

definitely

2298

01:45:05,109 --> 01:45:02,719

okay so for a pure mathematician who

2299

01:45:06,390 --> 01:45:05,119

seemingly doesn't care about reality

2300

01:45:09,590 --> 01:45:06,400

it's supposed to be discontinued again

2301

01:45:13,109 --> 01:45:09,600

the valuable math is the math that i can

2302

01:45:14,790 --> 01:45:13,119

or the more valuable math

2303

01:45:20,870 --> 01:45:14,800

is the math that i can turn into a

2304

01:45:25,669 --> 01:45:23,109

it's still pure math in the sense that

2305

01:45:29,189 --> 01:45:25,679

i'm not looking for an immediate or a

2306

01:45:29,199 --> 01:45:32,629

uh but

2307

01:45:38,070 --> 01:45:35,270

both from the application perspective

2308

01:45:39,830 --> 01:45:38,080

and from the pedagogical perspective

2309

01:45:42,950 --> 01:45:39,840

i still prefer

2310

01:45:44,950 --> 01:45:42,960

the map that the math that can be

2311

01:45:46,870 --> 01:45:44,960

implemented because the math that can be

2312

01:45:49,109 --> 01:45:46,880

implemented even if i'm not looking for

2313

01:45:51,030 --> 01:45:49,119

an immediate application

2314

01:45:52,709 --> 01:45:51,040

is there is the math that has a higher

2315

01:45:55,510 --> 01:45:52,719

chance

2316

01:45:57,750 --> 01:45:55,520

of being applied

2317

01:45:59,109 --> 01:45:57,760

because in the application you'll end up

2318

01:46:00,310 --> 01:45:59,119

computing

2319

01:46:02,310 --> 01:46:00,320

and also

2320

01:46:07,430 --> 01:46:02,320

from the teaching perspective from the

2321

01:46:07,440 --> 01:46:11,270

there is more value

2322

01:46:16,070 --> 01:46:13,830

to the education you give

2323

01:46:17,990 --> 01:46:16,080

if it comes with implementation because

2324

01:46:22,390 --> 01:46:18,000

you want your students to be able to

2325

01:46:26,950 --> 01:46:24,790

yes sorry what were you asking oh i was

2326

01:46:28,629 --> 01:46:26,960

saying you ultimately care about the

2327

01:46:32,709 --> 01:46:28,639

practical aspect of math even though

2328

01:46:38,709 --> 01:46:36,070

ultimately yes though possibly very

2329

01:46:43,109 --> 01:46:38,719

indirectly

2330

01:46:44,709 --> 01:46:43,119

so maybe the way the math i'm doing

2331

01:46:47,510 --> 01:46:44,719

or maybe the

2332

01:46:49,350 --> 01:46:47,520

maybe the way i care is in that the pure

2333

01:46:52,310 --> 01:46:49,360

math i'm doing

2334

01:46:55,430 --> 01:46:52,320

uh enables me to teach graduate students

2335

01:47:00,470 --> 01:46:55,440

who will then become college instructors

2336

01:47:00,480 --> 01:47:02,790

uh

2337

01:47:06,470 --> 01:47:04,629

actually

2338

01:47:07,669 --> 01:47:06,480

implement the mathematics they're

2339

01:47:09,910 --> 01:47:07,679

learning

2340

01:47:11,830 --> 01:47:09,920

so i mean it it doesn't have to be

2341

01:47:13,990 --> 01:47:11,840

immediate and direct

2342

01:47:16,470 --> 01:47:14,000

but yes i do care about

2343

01:47:19,189 --> 01:47:16,480

how at the end it gets applied

2344

01:47:21,669 --> 01:47:19,199

or how i get the end it it becomes

2345

01:47:23,350 --> 01:47:21,679

applicable

2346

01:47:26,310 --> 01:47:23,360

great now we just have some audience

2347

01:47:27,669 --> 01:47:26,320

questions i asked people beforehand

2348

01:47:29,430 --> 01:47:27,679

what are some questions you have for

2349

01:47:31,910 --> 01:47:29,440

professor jor barnetten so the

2350

01:47:34,149 --> 01:47:31,920

scientific mystical philosopher that's

2351

01:47:36,149 --> 01:47:34,159

the username he wants to know he or she

2352

01:47:42,790 --> 01:47:36,159

wants to know why the unreasonable

2353

01:47:46,550 --> 01:47:44,229

sorry

2354

01:47:49,990 --> 01:47:46,560

why is mathematics unreasonably

2355

01:47:55,510 --> 01:47:51,350

gee i don't know

2356

01:47:59,350 --> 01:47:57,430

uh

2357

01:48:01,750 --> 01:47:59,360

she may or may not be able to give you

2358

01:48:08,390 --> 01:48:01,760

an answer

2359

01:48:15,109 --> 01:48:11,510

yeah it's weird we live in a predictable

2360

01:48:18,629 --> 01:48:16,470

uh

2361

01:48:21,270 --> 01:48:18,639

right when we throw something up in the

2362

01:48:23,109 --> 01:48:21,280

air it always uh

2363

01:48:25,189 --> 01:48:23,119

shows this you know goes through the

2364

01:48:27,189 --> 01:48:25,199

same trajectory

2365

01:48:30,149 --> 01:48:27,199

uh

2366

01:48:33,990 --> 01:48:30,159

nearly i don't know i mean

2367

01:48:38,870 --> 01:48:36,550

roman gekwad wants to know have you ever

2368

01:48:44,550 --> 01:48:38,880

had your iq scored

2369

01:48:51,109 --> 01:48:47,189

no clue

2370

01:48:59,189 --> 01:48:54,629

you know iq scores are very limited in

2371

01:48:59,199 --> 01:49:02,149

you know are

2372

01:49:07,910 --> 01:49:05,430

you know there is a fun story

2373

01:49:12,550 --> 01:49:09,350

uh that i

2374

01:49:13,669 --> 01:49:12,560

i've never verified it but i heard it

2375

01:49:14,390 --> 01:49:13,679

okay

2376

01:49:20,790 --> 01:49:14,400

that

2377

01:49:26,629 --> 01:49:24,390

when the people who introduced iq tests

2378

01:49:28,629 --> 01:49:26,639

first introduced them they run them on

2379

01:49:31,510 --> 01:49:28,639

test subjects

2380

01:49:39,350 --> 01:49:33,910

the women the females

2381

01:49:43,350 --> 01:49:41,589

that was back in the 50s or i don't know

2382

01:49:47,030 --> 01:49:43,360

exactly when but there was a long time

2383

01:49:49,750 --> 01:49:47,040

ago they figured hey that's impossible

2384

01:49:51,830 --> 01:49:49,760

uh and then they tweaked the tests again

2385

01:49:54,470 --> 01:49:51,840

a bit they changed the nature of the

2386

01:49:56,950 --> 01:49:54,480

questions they asked them differently

2387

01:50:02,709 --> 01:49:56,960

until they finally were able

2388

01:50:05,750 --> 01:50:02,719

to uh to make um uh men uh equal or

2389

01:50:08,229 --> 01:50:05,760

maybe better i don't know than women

2390

01:50:12,149 --> 01:50:08,239

and again this is true

2391

01:50:15,189 --> 01:50:12,159

to a certain system of education in a

2392

01:50:16,950 --> 01:50:15,199

certain time

2393

01:50:19,669 --> 01:50:16,960

right

2394

01:50:22,070 --> 01:50:19,679

men and women did not receive the same

2395

01:50:22,950 --> 01:50:22,080

education

2396

01:50:25,350 --> 01:50:22,960

uh

2397

01:50:27,589 --> 01:50:25,360

it would have been easy to do to

2398

01:50:28,550 --> 01:50:27,599

distinguish

2399

01:50:31,030 --> 01:50:28,560

because

2400

01:50:33,030 --> 01:50:31,040

they came as as their backgrounds were

2401  
01:50:36,229 --> 01:50:33,040  
different

2402  
01:50:37,589 --> 01:50:36,239  
uh so you could arrange

2403  
01:50:39,510 --> 01:50:37,599  
uh

2404  
01:50:40,790 --> 01:50:39,520  
such things

2405  
01:50:42,550 --> 01:50:40,800  
okay

2406  
01:50:50,709 --> 01:50:42,560  
uh

2407  
01:50:54,709 --> 01:50:53,109  
that's about the value of iq

2408  
01:50:56,709 --> 01:50:54,719  
of iq scores

2409  
01:50:58,870 --> 01:50:56,719  
okay they were

2410  
01:51:02,070 --> 01:50:58,880  
i mean

2411  
01:51:03,910 --> 01:51:02,080  
to some extent they measured something

2412  
01:51:06,149 --> 01:51:03,920  
to some extent they were cooked to

2413  
01:51:10,550 --> 01:51:06,159

measure whatever people wanted them to

2414

01:51:13,990 --> 01:51:12,070

not much to learn from these

2415

01:51:15,669 --> 01:51:14,000

measurements

2416

01:51:18,550 --> 01:51:15,679

tori cole has

2417

01:51:21,589 --> 01:51:18,560

a question what do you think of biology

2418

01:51:23,510 --> 01:51:21,599

slash psychology slash philosophy

2419

01:51:25,669 --> 01:51:23,520

i think they're fun i think they're

2420

01:51:27,990 --> 01:51:25,679

foundational to understanding myself and

2421

01:51:29,990 --> 01:51:28,000

therefore my experience of the universe

2422

01:51:31,830 --> 01:51:30,000

do you think you would gain much of an

2423

01:51:34,310 --> 01:51:31,840

understanding

2424

01:51:37,750 --> 01:51:34,320

of an exploration from those fields to

2425

01:51:44,390 --> 01:51:39,830

again biology

2426  
01:51:47,589 --> 01:51:45,189  
i mean

2427  
01:51:51,510 --> 01:51:47,599  
they're all interesting fields i am not

2428  
01:51:56,229 --> 01:51:54,709  
what more to say you know

2429  
01:51:57,910 --> 01:51:56,239  
do you think there are insights there

2430  
01:52:00,310 --> 01:51:57,920  
that if you were to read a biology book

2431  
01:52:01,430 --> 01:52:00,320  
a psychology book perhaps a philosophy

2432  
01:52:03,030 --> 01:52:01,440  
book

2433  
01:52:04,470 --> 01:52:03,040  
do you think there are insights to be

2434  
01:52:09,910 --> 01:52:04,480  
gleaned from there that you can then

2435  
01:52:09,920 --> 01:52:14,709  
there are connections here and there

2436  
01:52:14,719 --> 01:52:18,629  
um

2437  
01:52:23,830 --> 01:52:20,709  
much of mathematics is independent of

2438  
01:52:25,630 --> 01:52:25,270

uh

2439

01:52:28,870 --> 01:52:25,640

so

2440

01:52:33,430 --> 01:52:30,870

obviously

2441

01:52:36,149 --> 01:52:33,440

biology motivates parts of mathematics

2442

01:52:40,229 --> 01:52:36,159

so parts of mathematics

2443

01:52:46,070 --> 01:52:42,950

you know are about modeling biological

2444

01:52:49,510 --> 01:52:47,109

when we

2445

01:52:52,550 --> 01:52:49,520

compute the fibonacci numbers we give

2446

01:52:54,070 --> 01:52:52,560

examples of uh the reproduction rules of

2447

01:52:55,830 --> 01:52:54,080

rabbits

2448

01:52:57,589 --> 01:52:55,840

okay

2449

01:53:00,870 --> 01:52:57,599

and and then there is much more like

2450

01:53:04,629 --> 01:53:00,880

that and and then um

2451

01:53:07,669 --> 01:53:06,149

uh

2452

01:53:09,589 --> 01:53:07,679

but

2453

01:53:12,790 --> 01:53:09,599

and likewise and and and of course

2454

01:53:14,310 --> 01:53:12,800

philosophy so you know there are

2455

01:53:16,310 --> 01:53:14,320

bits of mathematics of great

2456

01:53:19,750 --> 01:53:16,320

philosophical values so

2457

01:53:20,629 --> 01:53:19,760

you know gideon's theorem says

2458

01:53:22,629 --> 01:53:20,639

uh

2459

01:53:25,510 --> 01:53:22,639

that there are all there will always be

2460

01:53:28,229 --> 01:53:25,520

things we do not we will not know

2461

01:53:31,510 --> 01:53:28,239

okay or said diff or or differently i

2462

01:53:34,070 --> 01:53:31,520

know there is no algorithm to decide

2463

01:53:41,270 --> 01:53:37,910

to find the proofs of theorems

2464

01:53:43,350 --> 01:53:41,280

uh these things have philosophical value

2465

01:53:44,790 --> 01:53:43,360

okay

2466

01:53:48,149 --> 01:53:44,800

uh

2467

01:53:49,030 --> 01:53:48,159

for most mathematicians it's not

2468

01:53:59,910 --> 01:53:49,040

a

2469

01:54:00,950 --> 01:53:59,920

benefits very little

2470

01:54:01,910 --> 01:54:00,960

if any

2471

01:54:04,229 --> 01:54:01,920

from the

2472

01:54:05,830 --> 01:54:04,239

from contact with biology

2473

01:54:11,750 --> 01:54:05,840

uh

2474

01:54:16,470 --> 01:54:13,910

okay phil thomas wants to know what led

2475

01:54:19,030 --> 01:54:16,480

him what led you professor to the field

2476

01:54:21,030 --> 01:54:19,040

of mathematics and is your field

2477

01:54:28,470 --> 01:54:21,040

something you think virtually anyone can

2478

01:54:28,480 --> 01:54:32,470

what led me there

2479

01:54:35,510 --> 01:54:33,430

you know

2480

01:54:37,830 --> 01:54:35,520

it's a question about my life story

2481

01:54:40,070 --> 01:54:37,840

right so what led me there is essentia

2482

01:54:48,310 --> 01:54:40,080

is is

2483

01:54:53,030 --> 01:54:50,750

a sequence of uh coincidences and

2484

01:54:54,870 --> 01:54:53,040

misunderstandings i don't know

2485

01:54:55,830 --> 01:54:54,880

a number of things but

2486

01:54:56,790 --> 01:54:55,840

so

2487

01:54:59,669 --> 01:54:56,800

um

2488

01:55:01,430 --> 01:54:59,679

to some extent to some extent i was good

2489

01:55:03,350 --> 01:55:01,440

at that

2490

01:55:11,990 --> 01:55:03,360

and that

2491

01:55:14,030 --> 01:55:12,000

many things right people tend to do what

2492

01:55:15,589 --> 01:55:14,040

they're good at

2493

01:55:18,149 --> 01:55:15,599

misunderstandings you said

2494

01:55:21,109 --> 01:55:18,159

misunderstandings as well yes to some

2495

01:55:23,270 --> 01:55:21,119

extent uh

2496

01:55:25,030 --> 01:55:23,280

i misunderstood math

2497

01:55:27,350 --> 01:55:25,040

so

2498

01:55:31,830 --> 01:55:27,360

you know there was a time that i really

2499

01:55:34,950 --> 01:55:31,840

liked uh computers and electronics

2500

01:55:36,790 --> 01:55:34,960

i uh at some point

2501

01:55:39,109 --> 01:55:36,800

realized that there is a lot of kind of

2502

01:55:40,390 --> 01:55:39,119

hard work in it

2503

01:55:43,189 --> 01:55:40,400

so

2504

01:55:47,910 --> 01:55:45,589

writing a computer program is very hard

2505

01:55:49,510 --> 01:55:47,920

you have to write hundreds of lines of

2506

01:55:51,669 --> 01:55:49,520

code and then

2507

01:55:54,310 --> 01:55:51,679

debug them and they whatever and

2508

01:55:56,550 --> 01:55:54,320

similarly for electronics right you have

2509

01:55:59,350 --> 01:55:56,560

to place those transistors on the board

2510

01:56:01,350 --> 01:55:59,360

and solder them together and

2511

01:56:03,109 --> 01:56:01,360

solder them together and

2512

01:56:05,270 --> 01:56:03,119

and you always get it wrong and you know

2513

01:56:07,510 --> 01:56:05,280

there is a lot of hard work where

2514

01:56:10,709 --> 01:56:07,520

mathematics is so much easier all you

2515

01:56:12,470 --> 01:56:10,719

have to do is to prove theorems

2516

01:56:16,070 --> 01:56:12,480

that was a complete misunderstanding i

2517

01:56:17,589 --> 01:56:16,080

mean i thought it was like much purer

2518

01:56:19,910 --> 01:56:17,599

uh i didn't

2519

01:56:23,189 --> 01:56:19,920

at the time i didn't realize how much

2520

01:56:24,950 --> 01:56:23,199

hard work is involved

2521

01:56:27,109 --> 01:56:24,960

so in some sense i got there i go to

2522

01:56:29,750 --> 01:56:27,119

mathematics by misunderstanding by being

2523

01:56:31,270 --> 01:56:29,760

lazy and not realizing that

2524

01:56:33,750 --> 01:56:31,280

i'm i'm

2525

01:56:35,750 --> 01:56:33,760

getting trapped into into a place where

2526

01:56:38,790 --> 01:56:35,760

laziness is is not

2527

01:56:41,270 --> 01:56:38,800

it is is not always enough

2528

01:56:44,470 --> 01:56:41,280

and also at the end i ended up liking

2529

01:56:48,149 --> 01:56:44,480

those parts that i first thought i was

2530

01:56:50,550 --> 01:56:48,159

going away from namely computation

2531

01:56:52,870 --> 01:56:50,560

so i ended up i mean computation to me

2532

01:56:54,870 --> 01:56:52,880

was like a childhood thing and a later

2533

01:56:56,709 --> 01:56:54,880

acquired taste

2534

01:56:58,550 --> 01:56:56,719

there was a period in between when in

2535

01:57:02,070 --> 01:56:58,560

between when i thought i was pure i

2536

01:57:02,080 --> 01:57:05,350

um

2537

01:57:09,109 --> 01:57:07,750

right what else did i answer or did i

2538

01:57:11,830 --> 01:57:09,119

mean there was a second part to the

2539

01:57:13,750 --> 01:57:11,840

question do you believe that your field

2540

01:57:15,189 --> 01:57:13,760

either the field of mathematics or your

2541

01:57:17,189 --> 01:57:15,199

subfield the one that you're working in

2542

01:57:19,270 --> 01:57:17,199

currently do you feel that your field is

2543

01:57:22,229 --> 01:57:19,280

something that virtually anyone can

2544

01:57:22,239 --> 01:57:25,589

no

2545

01:57:33,589 --> 01:57:26,390

uh

2546

01:57:42,950 --> 01:57:36,830

some

2547

01:57:47,510 --> 01:57:44,709

everybody can learn

2548

01:57:49,669 --> 01:57:47,520

and everybody should learn

2549

01:57:54,470 --> 01:57:49,679

and maybe it's more

2550

01:57:57,189 --> 01:57:54,480

than what is taught in uh

2551  
01:58:00,390 --> 01:57:57,199  
in our current educational system

2552  
01:58:01,669 --> 01:58:00,400  
education system okay

2553  
01:58:03,350 --> 01:58:01,679  
uh

2554  
01:58:12,070 --> 01:58:03,360  
but

2555  
01:58:17,589 --> 01:58:13,189  
you know i

2556  
01:58:17,599 --> 01:58:21,189  
okay

2557  
01:58:29,510 --> 01:58:21,990  
the

2558  
01:58:32,310 --> 01:58:29,520  
which he knows things

2559  
01:58:35,910 --> 01:58:32,320  
i'll never get there

2560  
01:58:36,870 --> 01:58:35,920  
it's not i'm not talented enough to get

2561  
01:58:40,470 --> 01:58:36,880  
there

2562  
01:58:43,270 --> 01:58:40,480  
it might be that in my 30 years in the

2563  
01:58:45,750 --> 01:58:43,280

subject i've learned things that uh

2564

01:58:49,350 --> 01:58:45,760

most people

2565

01:58:56,149 --> 01:58:49,360

also wouldn't be able to catch up with

2566

01:58:59,990 --> 01:58:57,430

you know

2567

01:59:01,589 --> 01:59:00,000

there is the mushizuki proof of the abc

2568

01:59:03,750 --> 01:59:01,599

conjecture

2569

01:59:06,470 --> 01:59:03,760

disputed

2570

01:59:08,950 --> 01:59:06,480

okay moshizuki claims it's a proof other

2571

01:59:10,950 --> 01:59:08,960

people think it isn't

2572

01:59:13,669 --> 01:59:10,960

i will never be in the position to

2573

01:59:17,589 --> 01:59:13,679

understand that

2574

01:59:21,830 --> 01:59:20,149

possibly if i started early enough i'm

2575

01:59:24,070 --> 01:59:21,840

not even sure

2576

01:59:26,950 --> 01:59:24,080

i happen to know moshizuki i remember

2577

01:59:29,750 --> 01:59:26,960

him when he was young we we were friends

2578

01:59:31,109 --> 01:59:29,760

when like we went we're went to graduate

2579

01:59:32,550 --> 01:59:31,119

school together

2580

01:59:35,669 --> 01:59:32,560

so i uh

2581

01:59:38,470 --> 01:59:35,679

so i remember him when he was young

2582

01:59:40,550 --> 01:59:38,480

he was smarter and faster than me

2583

01:59:42,470 --> 01:59:40,560

it's conceivable that after 20 years

2584

01:59:45,030 --> 01:59:42,480

he's gone so far

2585

01:59:47,910 --> 01:59:45,040

that i will never be able to catch up

2586

01:59:49,430 --> 01:59:47,920

it's equally possible that

2587

01:59:52,229 --> 01:59:49,440

there are people who would never be able

2588

01:59:52,930 --> 01:59:52,239

to catch up with me

2589

01:59:55,109 --> 01:59:52,940

um

2590

01:59:57,990 --> 01:59:55,119

[Music]

2591

02:00:01,910 --> 01:59:58,000

they said

2592

02:00:01,920 --> 02:00:05,669

is useful to everybody

2593

02:00:10,629 --> 02:00:07,750

you know

2594

02:00:12,310 --> 02:00:10,639

we're we're now in the in the midst of a

2595

02:00:14,790 --> 02:00:12,320

pandemic

2596

02:00:16,790 --> 02:00:14,800

understanding what's the exponential

2597

02:00:21,750 --> 02:00:16,800

function

2598

02:00:25,350 --> 02:00:23,669

is basic knowledge is something that

2599

02:00:26,709 --> 02:00:25,360

every human should

2600

02:00:29,350 --> 02:00:26,719

should have

2601  
02:00:31,189 --> 02:00:29,360  
because it actually dictates if it tells

2602  
02:00:33,189 --> 02:00:31,199  
us something

2603  
02:00:35,750 --> 02:00:33,199  
about how to behave

2604  
02:00:37,910 --> 02:00:35,760  
uh at this time

2605  
02:00:41,350 --> 02:00:37,920  
uh

2606  
02:00:43,030 --> 02:00:41,360  
likewise making various probabilistic

2607  
02:00:46,550 --> 02:00:43,040  
estimates

2608  
02:00:52,870 --> 02:00:49,510  
if the chance of such and such type of

2609  
02:00:55,750 --> 02:00:52,880  
side effects is is one in a million what

2610  
02:00:57,750 --> 02:00:55,760  
does it mean

2611  
02:01:00,149 --> 02:00:57,760  
what does one in a million means in

2612  
02:01:01,830 --> 02:01:00,159  
practical term for me terms for me

2613  
02:01:04,149 --> 02:01:01,840

should i fear it

2614

02:01:07,189 --> 02:01:04,159

or is it so remote that i have that i

2615

02:01:14,070 --> 02:01:11,109

so basic numeracy is is is is an

2616

02:01:15,189 --> 02:01:14,080

absolute necessary ingredient and for

2617

02:01:19,589 --> 02:01:15,199

everyone

2618

02:01:21,430 --> 02:01:19,599

when you mentioned that you'll never be

2619

02:01:22,629 --> 02:01:21,440

able to catch up to whitten and may

2620

02:01:25,030 --> 02:01:22,639

perhaps some people won't be able to

2621

02:01:27,189 --> 02:01:25,040

catch up to you and so on

2622

02:01:29,189 --> 02:01:27,199

what is that a function of biology you

2623

02:01:31,430 --> 02:01:29,199

mentioned the word talent so is it is

2624

02:01:33,589 --> 02:01:31,440

that just innate is

2625

02:01:36,390 --> 02:01:33,599

is what's innate called intelligence is

2626

02:01:37,910 --> 02:01:36,400

that associated with iq like what are

2627

02:01:40,070 --> 02:01:37,920

you referring to when you say you won't

2628

02:01:43,350 --> 02:01:40,080

be able to catch up

2629

02:01:45,589 --> 02:01:43,360

it's a number of things

2630

02:01:47,990 --> 02:01:45,599

you can call it talent

2631

02:01:50,870 --> 02:01:48,000

you can call it iq if you wish but of

2632

02:01:53,109 --> 02:01:50,880

course there is no numerical measurement

2633

02:02:01,350 --> 02:01:53,119

and it's a much much more complicated

2634

02:02:08,870 --> 02:02:03,750

you know so much of

2635

02:02:12,790 --> 02:02:10,790

depends on how much you concentrate on

2636

02:02:15,750 --> 02:02:12,800

mathematics

2637

02:02:20,149 --> 02:02:15,760

so you know uh

2638

02:02:25,109 --> 02:02:22,629

if at a certain part of your life you're

2639

02:02:28,870 --> 02:02:25,119

able to completely isolate yourself and

2640

02:02:31,510 --> 02:02:28,880

think on nothing but mathematics

2641

02:02:33,910 --> 02:02:31,520

you'll end up knowing more mathematics

2642

02:02:35,030 --> 02:02:33,920

than if you are also a human a human

2643

02:02:39,350 --> 02:02:35,040

along

2644

02:02:40,550 --> 02:02:39,360

okay uh

2645

02:02:53,470 --> 02:02:40,560

so

2646

02:02:57,910 --> 02:02:55,669

circumstance and

2647

02:02:59,669 --> 02:02:57,920

uh

2648

02:03:03,189 --> 02:02:59,679

and luck

2649

02:03:09,589 --> 02:03:06,870

in some sense being narrow-minded

2650

02:03:12,149 --> 02:03:09,599

so now being narrow-minded helps in

2651  
02:03:15,430 --> 02:03:12,159  
certain ways

2652  
02:03:18,709 --> 02:03:17,669  
speaking of eric weinstein you mentioned

2653  
02:03:19,910 --> 02:03:18,719  
him

2654  
02:03:20,709 --> 02:03:19,920  
okay so

2655  
02:03:25,510 --> 02:03:20,719  
so

2656  
02:03:28,629 --> 02:03:25,520  
talent for certain kind of things and

2657  
02:03:30,149 --> 02:03:28,639  
great fear of others

2658  
02:03:32,310 --> 02:03:30,159  
and

2659  
02:03:35,270 --> 02:03:32,320  
maybe he would have been a much more

2660  
02:03:38,229 --> 02:03:35,280  
famous mathematician physicist now

2661  
02:03:40,830 --> 02:03:38,239  
if if it wasn't for these

2662  
02:03:44,550 --> 02:03:40,840  
coincidences

2663  
02:03:48,390 --> 02:03:45,669

i don't know

2664

02:03:54,950 --> 02:03:50,069

you could call it

2665

02:03:57,350 --> 02:03:54,960

uh learn you can call it many things but

2666

02:03:59,589 --> 02:03:57,360

it's a very complicated combination of

2667

02:04:01,830 --> 02:03:59,599

things

2668

02:04:03,830 --> 02:04:01,840

tyler goldstein has a question

2669

02:04:05,910 --> 02:04:03,840

do you think we need to make new

2670

02:04:07,990 --> 02:04:05,920

research institutions that aren't linked

2671

02:04:11,109 --> 02:04:08,000

to academia

2672

02:04:12,709 --> 02:04:11,119

and i imagine what he's referring to

2673

02:04:14,390 --> 02:04:12,719

is something that weinstein has brought

2674

02:04:16,709 --> 02:04:14,400

up in wolfram as well

2675

02:04:18,550 --> 02:04:16,719

they're not huge fans of the peer review

2676

02:04:20,390 --> 02:04:18,560

process or at least they're not huge

2677

02:04:21,830 --> 02:04:20,400

fans of only

2678

02:04:23,270 --> 02:04:21,840

thinking that work

2679

02:04:25,589 --> 02:04:23,280

is worth it if it's gone through the

2680

02:04:27,510 --> 02:04:25,599

peer review process

2681

02:04:29,589 --> 02:04:27,520

and

2682

02:04:31,669 --> 02:04:29,599

while that's associated with academia

2683

02:04:40,550 --> 02:04:31,679

i'm curious if you have any thoughts as

2684

02:04:44,149 --> 02:04:42,470

well there are things outside of

2685

02:04:46,709 --> 02:04:44,159

academia

2686

02:04:50,470 --> 02:04:48,950

arguably most research is done outside

2687

02:04:52,310 --> 02:04:50,480

of academia

2688

02:04:55,350 --> 02:04:52,320

i mean you know there are a lot of a lot

2689

02:04:56,950 --> 02:04:55,360

of research is done inside companies

2690

02:04:59,430 --> 02:04:56,960

inside

2691

02:05:03,189 --> 02:04:59,440

well a lot of research is done outside

2692

02:05:03,199 --> 02:05:08,149

um

2693

02:05:12,310 --> 02:05:10,470

but overall i think the system is

2694

02:05:14,390 --> 02:05:12,320

reasonable

2695

02:05:17,910 --> 02:05:14,400

sorry overall you think the system is i

2696

02:05:19,270 --> 02:05:17,920

think the system is reasonable

2697

02:05:23,589 --> 02:05:19,280

so

2698

02:05:26,069 --> 02:05:23,599

uh you know you can um

2699

02:05:27,669 --> 02:05:26,079

say bad things as much as you want about

2700

02:05:32,390 --> 02:05:27,679

peer review

2701

02:05:32,400 --> 02:05:36,870

it's better than having no review

2702

02:05:36,880 --> 02:05:41,030

um

2703

02:05:44,069 --> 02:05:42,870

you can say

2704

02:05:46,229 --> 02:05:44,079

uh

2705

02:05:47,990 --> 02:05:46,239

maybe mathematical should be more

2706

02:05:50,790 --> 02:05:48,000

hierarchical

2707

02:05:51,830 --> 02:05:50,800

okay there should be big bosses

2708

02:05:54,310 --> 02:05:51,840

who

2709

02:05:56,069 --> 02:05:54,320

determine which theorems we should be

2710

02:06:00,550 --> 02:05:56,079

proving

2711

02:06:04,069 --> 02:06:01,669

have their

2712

02:06:06,870 --> 02:06:04,079

smaller bosses who would be responsible

2713

02:06:09,109 --> 02:06:06,880

to specific theorems and they would be

2714

02:06:11,109 --> 02:06:09,119

the big bosses of other people who would

2715

02:06:12,870 --> 02:06:11,119

be proving dilemmas

2716

02:06:15,350 --> 02:06:12,880

you could say something like that it

2717

02:06:17,510 --> 02:06:15,360

sounds like it sounds ridiculous it

2718

02:06:18,950 --> 02:06:17,520

would work just as ridiculously as it

2719

02:06:21,750 --> 02:06:18,960

sounds

2720

02:06:23,350 --> 02:06:21,760

current system is

2721

02:06:25,030 --> 02:06:23,360

you know

2722

02:06:29,910 --> 02:06:25,040

given

2723

02:06:31,669 --> 02:06:29,920

reasonably good i believe there are some

2724

02:06:33,830 --> 02:06:31,679

arguments to say that

2725

02:06:36,229 --> 02:06:33,840

the what you just outlined is

2726

02:06:39,510 --> 02:06:36,239

somewhat like it happens given grant

2727

02:06:41,669 --> 02:06:39,520

agencies they have some field that they

2728

02:06:43,589 --> 02:06:41,679

fund and so then the research tends to

2729

02:06:46,390 --> 02:06:43,599

go toward there so you can view them as

2730

02:06:48,470 --> 02:06:46,400

the large boss and i believe lee smallin

2731

02:06:50,629 --> 02:06:48,480

makes some arguments saying that that's

2732

02:06:52,790 --> 02:06:50,639

why string theory is as large as as it

2733

02:06:54,390 --> 02:06:52,800

is even though it shouldn't be because

2734

02:06:56,629 --> 02:06:54,400

we haven't seen much success from it and

2735

02:06:58,709 --> 02:06:56,639

so on so do you see what you just

2736

02:07:00,790 --> 02:06:58,719

outlined as the ridiculous scenario do

2737

02:07:06,790 --> 02:07:00,800

you see that as having any bearing to

2738

02:07:06,800 --> 02:07:09,109

so

2739

02:07:09,119 --> 02:07:18,149

yes of course there is bias

2740

02:07:23,430 --> 02:07:21,189

generated by the granting agencies by

2741

02:07:25,990 --> 02:07:23,440

the powerful people

2742

02:07:29,030 --> 02:07:26,000

be them be them the writing granting

2743

02:07:31,189 --> 02:07:29,040

agencies or the editorial boards of

2744

02:07:33,750 --> 02:07:31,199

journals

2745

02:07:37,030 --> 02:07:33,760

so you know

2746

02:07:40,069 --> 02:07:37,040

if you publish if you have a result

2747

02:07:43,030 --> 02:07:40,079

uh that somebody on the editorial board

2748

02:07:44,310 --> 02:07:43,040

of an excellent journal uh

2749

02:07:46,310 --> 02:07:44,320

likes

2750

02:07:48,390 --> 02:07:46,320

you know that's close to the field of

2751

02:07:50,550 --> 02:07:48,400

somebody in the editorial board of an

2752

02:07:52,470 --> 02:07:50,560

excellent excellent journal then your

2753

02:07:56,550 --> 02:07:52,480

result is much more likely to get

2754

02:07:58,470 --> 02:07:56,560

published in this uh excellent journal

2755

02:08:01,830 --> 02:07:58,480

and then you're much more likely to get

2756

02:08:04,550 --> 02:08:01,840

tenure and then

2757

02:08:06,629 --> 02:08:04,560

more work will be produced in that field

2758

02:08:09,030 --> 02:08:06,639

and you'll advise students who will

2759

02:08:11,189 --> 02:08:09,040

produce even more more work on that

2760

02:08:16,470 --> 02:08:11,199

field

2761

02:08:16,480 --> 02:08:20,229

but

2762

02:08:25,270 --> 02:08:22,310

it's not clear that you can think of a

2763

02:08:27,589 --> 02:08:25,280

better alternative

2764

02:08:30,149 --> 02:08:27,599

and also

2765

02:08:33,750 --> 02:08:30,159

there is still some amount of academic

2766

02:08:37,510 --> 02:08:33,760

freedom so the granting agency

2767

02:08:41,270 --> 02:08:37,520

decides once every five years

2768

02:08:49,109 --> 02:08:46,069

in those five years some of my time i do

2769

02:08:51,430 --> 02:08:49,119

what is necessary to get my next grant

2770

02:08:54,470 --> 02:08:51,440

but some of the time i also do things

2771

02:08:55,990 --> 02:08:54,480

that i think are useful that i think are

2772

02:08:58,390 --> 02:08:56,000

useful

2773

02:08:59,350 --> 02:08:58,400

uh likewise

2774

02:09:02,709 --> 02:08:59,360

uh

2775

02:09:05,350 --> 02:09:02,719

you know some of my career

2776

02:09:09,589 --> 02:09:05,360

is is determined by which journal i

2777

02:09:12,470 --> 02:09:09,599

publish in but some is determined by

2778

02:09:14,069 --> 02:09:12,480

uh other factors

2779

02:09:16,390 --> 02:09:14,079

okay by the results that aren't

2780

02:09:19,750 --> 02:09:16,400

published by the lectures that i give in

2781

02:09:23,109 --> 02:09:19,760

conferences in china you know

2782

02:09:24,870 --> 02:09:23,119

it's much more multi-dimensional

2783

02:09:27,189 --> 02:09:24,880

than uh

2784

02:09:31,830 --> 02:09:27,199

than just having a boss and the boss is

2785

02:09:35,830 --> 02:09:33,910

even the fact that the editorial boards

2786

02:09:39,030 --> 02:09:35,840

are different than the review boards of

2787

02:09:40,950 --> 02:09:39,040

the granting agencies allows make some

2788

02:09:43,910 --> 02:09:40,960

variety

2789

02:09:47,350 --> 02:09:43,920  
and again what is the alternative

2790

02:09:52,149 --> 02:09:50,069  
one stupid alternative would be to say

2791

02:09:54,709 --> 02:09:52,159  
to allow anyone to say

2792

02:09:57,910 --> 02:09:54,719  
i am a mathematician

2793

02:10:01,350 --> 02:09:57,920  
uh here is my proof that

2794

02:10:03,750 --> 02:10:01,360  
pi is rational

2795

02:10:05,910 --> 02:10:03,760  
or that you can

2796

02:10:08,709 --> 02:10:05,920  
divide you know

2797

02:10:10,310 --> 02:10:08,719  
here is my proof of the uh goldbach

2798

02:10:13,189 --> 02:10:10,320  
conjecture

2799

02:10:15,350 --> 02:10:13,199  
who's arguing with me i'm saying it's a

2800

02:10:20,390 --> 02:10:15,360  
proof

2801

02:10:25,750 --> 02:10:23,189

it's much better not to lose control

2802

02:10:27,510 --> 02:10:25,760

completely

2803

02:10:29,669 --> 02:10:27,520

you just use the word mathematician and

2804

02:10:31,350 --> 02:10:29,679

i'm curious what do you see as a

2805

02:10:33,109 --> 02:10:31,360

mathematician is it someone who's a

2806

02:10:35,669 --> 02:10:33,119

professor of math is this someone who

2807

02:10:37,750 --> 02:10:35,679

gets their masters or phd do you have to

2808

02:10:39,510 --> 02:10:37,760

frequently publish research in order for

2809

02:10:40,790 --> 02:10:39,520

you to call yourself a mathematician

2810

02:10:43,830 --> 02:10:40,800

like what gives

2811

02:10:47,350 --> 02:10:43,840

obviously it's a nebulous term but it's

2812

02:10:49,589 --> 02:10:47,360

not extremely amorphous it's defined

2813

02:10:53,990 --> 02:10:49,599

so what do you define it as

2814

02:11:02,950 --> 02:10:55,030

you know

2815

02:11:09,430 --> 02:11:05,270

many definitions don't have sharp

2816

02:11:12,390 --> 02:11:09,440

boundaries in fact only in mathematics

2817

02:11:14,709 --> 02:11:12,400

uh there are sharp boundaries between

2818

02:11:17,270 --> 02:11:14,719

things like either

2819

02:11:20,229 --> 02:11:17,280

the series is convergent or it is not

2820

02:11:21,750 --> 02:11:20,239

convergent but only and there is a very

2821

02:11:24,310 --> 02:11:21,760

very specific

2822

02:11:26,790 --> 02:11:24,320

uh criteria to decide only in

2823

02:11:28,950 --> 02:11:26,800

mathematics there are

2824

02:11:30,709 --> 02:11:28,960

uh sharp boundaries and now you're

2825

02:11:32,310 --> 02:11:30,719

asking a meta-mathematical question

2826

02:11:33,830 --> 02:11:32,320

you're asking a question about

2827

02:11:36,390 --> 02:11:33,840

mathematics not a question in

2828

02:11:38,550 --> 02:11:36,400

mathematics so there aren't

2829

02:11:39,990 --> 02:11:38,560

sharp boundaries so basically all of the

2830

02:11:41,990 --> 02:11:40,000

above you know

2831

02:11:44,709 --> 02:11:42,000

if you teach mathematics if you think a

2832

02:11:47,510 --> 02:11:44,719

lot about mathematics if your way of

2833

02:11:50,830 --> 02:11:47,520

thought is abstraction

2834

02:11:50,840 --> 02:11:54,950

proof um

2835

02:12:00,709 --> 02:11:57,589

you know then that's mathematics but

2836

02:12:03,350 --> 02:12:00,719

but but you can always

2837

02:12:05,589 --> 02:12:03,360

you can always find the borderline

2838

02:12:07,830 --> 02:12:05,599

things that will be hard to decide

2839

02:12:09,270 --> 02:12:07,840

here's a reason why i'm asking because

2840

02:12:11,350 --> 02:12:09,280

not everyone can call themselves a

2841

02:12:13,589 --> 02:12:11,360

doctor i know that some people they get

2842

02:12:15,350 --> 02:12:13,599

their md and then they're no longer

2843

02:12:16,950 --> 02:12:15,360

practicing researchers they no longer

2844

02:12:18,870 --> 02:12:16,960

are connected with the field but then

2845

02:12:20,470 --> 02:12:18,880

they'll give health advice resting on

2846

02:12:21,910 --> 02:12:20,480

the laurel that they have an md and

2847

02:12:22,950 --> 02:12:21,920

they'll say well this comes from a

2848

02:12:25,350 --> 02:12:22,960

doctor

2849

02:12:27,270 --> 02:12:25,360

and i'm sure the same occurs in

2850

02:12:29,189 --> 02:12:27,280

mathematics though

2851

02:12:31,030 --> 02:12:29,199

to a much lesser degree same with

2852

02:12:33,109 --> 02:12:31,040

physics someone may say well i'm a

2853

02:12:36,149 --> 02:12:33,119

physicist because i

2854

02:12:37,990 --> 02:12:36,159

i have a degree from a university but

2855

02:12:40,229 --> 02:12:38,000

that in physics but that doesn't

2856

02:12:41,669 --> 02:12:40,239

necessarily make you a physicist doesn't

2857

02:12:43,669 --> 02:12:41,679

mean your physics works should be taken

2858

02:12:47,350 --> 02:12:43,679

more seriously because you have that

2859

02:12:52,470 --> 02:12:49,990

if you're so if you're looking for a

2860

02:12:54,550 --> 02:12:52,480

set of thumb rules

2861

02:12:57,510 --> 02:12:54,560

to decide uh

2862

02:12:59,510 --> 02:12:57,520

uh which experts are to be trusted and

2863

02:13:02,310 --> 02:12:59,520

which should not

2864

02:13:07,430 --> 02:13:02,320

be them experts in mathematics or

2865

02:13:13,910 --> 02:13:09,669

well the answer is these questions are

2866

02:13:13,920 --> 02:13:23,510

so you know in medicine uh

2867

02:13:28,470 --> 02:13:25,990

you probably have to look for the bigger

2868

02:13:30,870 --> 02:13:28,480

name doctors the more you know the more

2869

02:13:33,030 --> 02:13:30,880

established doctors because

2870

02:13:37,270 --> 02:13:33,040

the system actually does

2871

02:13:40,470 --> 02:13:37,280

on average promote the better people

2872

02:13:43,350 --> 02:13:40,480

even if not always

2873

02:13:46,149 --> 02:13:43,360

okay and you should look for

2874

02:13:47,910 --> 02:13:46,159

was it said by

2875

02:13:50,390 --> 02:13:47,920

most doctors

2876

02:13:52,709 --> 02:13:50,400

or by

2877

02:13:54,390 --> 02:13:52,719

one doctor who hasn't practiced for a

2878

02:13:57,830 --> 02:13:54,400

long time

2879

02:14:03,109 --> 02:13:59,589

and the same is in

2880

02:14:08,310 --> 02:14:05,270

uh

2881

02:14:11,270 --> 02:14:08,320

yes there are phd in mathematic people

2882

02:14:13,910 --> 02:14:11,280

with a phd in mathematics who who who

2883

02:14:16,229 --> 02:14:13,920

shouldn't have gotten their phd

2884

02:14:19,750 --> 02:14:16,239

yes there are people brilliant people

2885

02:14:22,229 --> 02:14:19,760

with bro who did real brilliant phd phds

2886

02:14:25,189 --> 02:14:22,239

in mathematics and 10 years later

2887

02:14:27,430 --> 02:14:25,199

uh lost their mind and are

2888

02:14:29,669 --> 02:14:27,440

speaking nonsense

2889

02:14:31,270 --> 02:14:29,679

i mean

2890

02:14:33,589 --> 02:14:31,280

it's

2891

02:14:37,030 --> 02:14:33,599

there is no look at this certificate and

2892

02:14:38,830 --> 02:14:37,040

if somebody has the certificate then

2893

02:14:41,750 --> 02:14:38,840

then they're

2894

02:14:43,510 --> 02:14:41,760

trustworthy ashley ship wants to know is

2895

02:14:45,589 --> 02:14:43,520

there a connection between not theory

2896

02:14:47,830 --> 02:14:45,599

and protein folding

2897

02:14:49,510 --> 02:14:47,840

and is it possible to use

2898

02:14:51,589 --> 02:14:49,520

well if so is it possible to use the

2899

02:14:53,830 --> 02:14:51,599

artificial intelligence research that

2900

02:14:57,990 --> 02:14:53,840

has been done on protein folding to

2901

02:15:03,510 --> 02:15:00,229

there is a connection between protein

2902

02:15:06,950 --> 02:15:03,520

folding and between dna and stuff like

2903

02:15:11,589 --> 02:15:09,589

in in not theory

2904

02:15:14,390 --> 02:15:11,599

uh people

2905

02:15:16,950 --> 02:15:14,400

it's not very strong

2906

02:15:20,629 --> 02:15:16,960

like in general

2907

02:15:20,639 --> 02:15:24,390

he

2908

02:15:29,510 --> 02:15:26,870

people like to say things about it but

2909

02:15:32,310 --> 02:15:29,520

the actual research at least my own

2910

02:15:35,990 --> 02:15:32,320

research is very different

2911

02:15:38,790 --> 02:15:36,000

from um

2912

02:15:43,510 --> 02:15:38,800

what you would end up doing with

2913

02:15:48,069 --> 02:15:46,790

of dnas or or proteins

2914

02:15:49,510 --> 02:15:48,079

by the way

2915

02:15:54,310 --> 02:15:49,520

uh

2916

02:15:57,109 --> 02:15:54,320

dna

2917

02:15:58,229 --> 02:15:57,119

the the study or

2918

02:16:00,229 --> 02:15:58,239

okay

2919

02:16:03,350 --> 02:16:00,239

so

2920

02:16:05,510 --> 02:16:03,360

dna molecules are really really really

2921

02:16:07,030 --> 02:16:05,520

really long strings

2922

02:16:09,189 --> 02:16:07,040

chromosomes

2923

02:16:11,350 --> 02:16:09,199

are really really really really really

2924

02:16:15,109 --> 02:16:11,360

long strings

2925

02:16:17,830 --> 02:16:15,119

namely they are of length billions

2926

02:16:21,189 --> 02:16:17,840

or the ratio of their length to their

2927

02:16:26,069 --> 02:16:21,199

width is billions

2928

02:16:33,509 --> 02:16:30,390

uh amino acids along them all right

2929

02:16:35,830 --> 02:16:33,519

and um

2930

02:16:37,270 --> 02:16:35,840

so so you know if you were to make it

2931

02:16:39,030 --> 02:16:37,280

out of probe

2932

02:16:41,830 --> 02:16:39,040

it would be

2933

02:16:43,349 --> 02:16:41,840

very very very thin rope which is very

2934

02:16:47,190 --> 02:16:43,359

very long

2935

02:16:53,349 --> 02:16:47,200

but yet this rope is compressed into a

2936

02:16:53,359 --> 02:16:57,110

so they get knotted

2937

02:17:01,429 --> 02:16:58,150

and

2938

02:17:04,389 --> 02:17:01,439

even your experience from a much smaller

2939

02:17:06,629 --> 02:17:04,399

knot so here's an electric cable if you

2940

02:17:09,190 --> 02:17:06,639

have a little bit of an experience with

2941

02:17:11,190 --> 02:17:09,200

letting loose of cables not tying them

2942

02:17:14,709 --> 02:17:11,200

nightly

2943

02:17:17,190 --> 02:17:14,719

nice as i tied this yeah if you let it

2944

02:17:19,750 --> 02:17:17,200

loose it gets melted

2945

02:17:23,110 --> 02:17:19,760

and it it's it's very it's nearly

2946

02:17:25,830 --> 02:17:23,120

impossible to untie

2947

02:17:31,190 --> 02:17:28,389

chromosomes are much worse they're much

2948

02:17:34,469 --> 02:17:31,200

much much longer

2949

02:17:38,070 --> 02:17:34,479

in in relative terms and they get

2950

02:17:40,870 --> 02:17:38,080

cramped into tiny tiny tiny spaces so

2951  
02:17:43,429 --> 02:17:40,880  
how come they don't get knotted

2952  
02:17:45,270 --> 02:17:43,439  
and if they do get knotted

2953  
02:17:46,230 --> 02:17:45,280  
how come

2954  
02:17:52,309 --> 02:17:46,240  
uh

2955  
02:17:55,270 --> 02:17:52,319  
parts of the life of a cell so when when

2956  
02:17:56,870 --> 02:17:55,280  
when cells um

2957  
02:17:59,509 --> 02:17:56,880  
uh split

2958  
02:18:02,389 --> 02:17:59,519  
uh they split they somehow managed to

2959  
02:18:04,629 --> 02:18:02,399  
untie themselves and disconnect

2960  
02:18:05,990 --> 02:18:04,639  
so how how is it happening so there must

2961  
02:18:09,030 --> 02:18:06,000  
be some

2962  
02:18:12,790 --> 02:18:09,040  
huge brain inside every cell

2963  
02:18:14,709 --> 02:18:12,800

uh that can untangle knots which are

2964

02:18:16,309 --> 02:18:14,719

much much much much much more

2965

02:18:20,230 --> 02:18:16,319

complicated

2966

02:18:23,110 --> 02:18:20,240

uh than the knots that uh

2967

02:18:24,709 --> 02:18:23,120

that you can untie

2968

02:18:27,429 --> 02:18:24,719

or you know the notes that you take

2969

02:18:28,469 --> 02:18:27,439

hours to untie with sometimes

2970

02:18:31,750 --> 02:18:28,479

okay

2971

02:18:34,309 --> 02:18:31,760

so there must be something there

2972

02:18:36,309 --> 02:18:34,319

and this and there is something there

2973

02:18:39,270 --> 02:18:36,319

and there are enzymes

2974

02:18:41,429 --> 02:18:39,280

that actually uh you know so

2975

02:18:42,790 --> 02:18:41,439

when when uh

2976

02:18:44,549 --> 02:18:42,800

uh

2977

02:18:49,270 --> 02:18:44,559

dna molecules

2978

02:18:52,389 --> 02:18:49,280

need to are not to untangle

2979

02:18:55,910 --> 02:18:52,399

there are enzymes that allow one

2980

02:18:59,190 --> 02:18:55,920

molecule to pass through the other so

2981

02:19:01,589 --> 02:18:59,200

basically you want to pass one string

2982

02:19:04,230 --> 02:19:01,599

through another so that they will come

2983

02:19:07,349 --> 02:19:04,240

to position there are enzymes that cut

2984

02:19:09,110 --> 02:19:07,359

this one temporarily it gets cut it

2985

02:19:11,429 --> 02:19:09,120

passes to the other side and it gets

2986

02:19:14,150 --> 02:19:11,439

reconnected

2987

02:19:16,709 --> 02:19:14,160

so in a sense

2988

02:19:20,709 --> 02:19:18,150

biology

2989

02:19:22,709 --> 02:19:20,719

invented anti-nautiorianza

2990

02:19:24,549 --> 02:19:22,719

enzymes

2991

02:19:27,589 --> 02:19:24,559

and and they are

2992

02:19:30,150 --> 02:19:27,599

necessary because of not theory

2993

02:19:33,270 --> 02:19:30,160

because if there were nots you wouldn't

2994

02:19:34,389 --> 02:19:33,280

be able to divide cells

2995

02:19:37,750 --> 02:19:34,399

uh

2996

02:19:40,870 --> 02:19:37,760

so so so so so biology invented some

2997

02:19:42,950 --> 02:19:40,880

some anti-node theory enzymes that allow

2998

02:19:45,509 --> 02:19:42,960

things to pass through each other that

2999

02:19:47,589 --> 02:19:45,519

nullify not theory so in some sense the

3000

02:19:52,630 --> 02:19:47,599

most interesting not theory that happens

3001

02:19:58,389 --> 02:19:56,309

that's a lovely story but in practice

3002

02:20:00,150 --> 02:19:58,399

there isn't much

3003

02:20:02,309 --> 02:20:00,160

jack desart wants to know is math a

3004

02:20:04,630 --> 02:20:02,319

human construct that we've devised to

3005

02:20:06,870 --> 02:20:04,640

better understand the universe or is

3006

02:20:09,429 --> 02:20:06,880

math a set of universal unchanging

3007

02:20:13,590 --> 02:20:09,439

principles i'm a human how would i know

3008

02:20:19,030 --> 02:20:16,469

you know how non-humans would say math

3009

02:20:21,190 --> 02:20:19,040

or how you know i

3010

02:20:22,469 --> 02:20:21,200

i don't know

3011

02:20:24,630 --> 02:20:22,479

but

3012

02:20:25,910 --> 02:20:24,640

this said

3013

02:20:27,750 --> 02:20:25,920

i mean i don't want to answer the

3014

02:20:30,550 --> 02:20:27,760

philosophical question but i want to

3015

02:20:32,550 --> 02:20:30,560

answer some there is some practical

3016

02:20:34,710 --> 02:20:32,560

things that comes out of it

3017

02:20:38,309 --> 02:20:34,720

every bit of math

3018

02:20:39,990 --> 02:20:38,319

so you know pick up a math book

3019

02:20:43,110 --> 02:20:40,000

here

3020

02:20:45,910 --> 02:20:43,120

every bit of math in this book

3021

02:20:48,710 --> 02:20:45,920

and not just this i mean every bit of

3022

02:20:52,630 --> 02:20:48,720

math in every book

3023

02:20:56,550 --> 02:20:54,070

ah

3024

02:20:59,429 --> 02:20:56,560

that's a good thing to remember it means

3025

02:21:01,990 --> 02:20:59,439

that there are no miracles

3026

02:21:05,270 --> 02:21:02,000

it means that

3027

02:21:05,280 --> 02:21:09,590

you know when you see a proof

3028

02:21:15,190 --> 02:21:10,830

and you have no

3029

02:21:17,510 --> 02:21:15,200

idea where could it come from

3030

02:21:23,110 --> 02:21:17,520

well you have no idea but somebody had

3031

02:21:23,120 --> 02:21:25,750

so

3032

02:21:32,870 --> 02:21:29,750

it's often extremely instructive

3033

02:21:34,870 --> 02:21:32,880

to try to reverse engineer somehow

3034

02:21:37,590 --> 02:21:34,880

not just understand the proof but

3035

02:21:40,070 --> 02:21:37,600

understand how

3036

02:21:44,230 --> 02:21:40,080

humans with all their failures could

3037

02:21:51,190 --> 02:21:45,830

so

3038

02:21:53,190 --> 02:21:51,200

math was entirely created by humans at

3039

02:21:55,190 --> 02:21:53,200

the end

3040

02:21:58,550 --> 02:21:55,200

do you think we don't spend enough time

3041

02:22:00,389 --> 02:21:58,560

in books talking about the missteps so

3042

02:22:02,389 --> 02:22:00,399

for example here's how the person

3043

02:22:05,750 --> 02:22:02,399

arrived at this proof they originally

3044

02:22:07,429 --> 02:22:05,760

thought of it like so this didn't work

3045

02:22:08,950 --> 02:22:07,439

or would that just bloat the book

3046

02:22:11,910 --> 02:22:08,960

unnecessarily

3047

02:22:13,030 --> 02:22:11,920

it would probably bloat the book

3048

02:22:19,030 --> 02:22:13,040

but

3049

02:22:23,670 --> 02:22:19,040

[Music]

3050

02:22:25,830 --> 02:22:23,680

and when i say motivate okay so

3051  
02:22:27,429 --> 02:22:25,840  
so some story is

3052  
02:22:29,349 --> 02:22:27,439  
should be told

3053  
02:22:31,110 --> 02:22:29,359  
like when you present

3054  
02:22:32,950 --> 02:22:31,120  
a proof

3055  
02:22:36,389 --> 02:22:32,960  
there should always be some plausible

3056  
02:22:38,950 --> 02:22:36,399  
discovery story how could this proof

3057  
02:22:41,670 --> 02:22:38,960  
have been found

3058  
02:22:43,510 --> 02:22:41,680  
it doesn't have to be a a historically

3059  
02:22:45,990 --> 02:22:43,520  
accurate

3060  
02:22:48,389 --> 02:22:46,000  
uh story

3061  
02:22:51,270 --> 02:22:48,399  
but but but but there has to be some

3062  
02:22:54,230 --> 02:22:51,280  
story explaining that this proof could

3063  
02:22:56,150 --> 02:22:54,240

have been found by humans it wasn't

3064

02:22:59,270 --> 02:22:56,160

created by some

3065

02:23:00,349 --> 02:22:59,280

supernatural entity

3066

02:23:02,870 --> 02:23:00,359

this question

3067

02:23:05,110 --> 02:23:02,880

cx770 asks does he believe in the

3068

02:23:08,309 --> 02:23:05,120

concept of god

3069

02:23:13,990 --> 02:23:11,030

okay this one's a tangential question

3070

02:23:15,990 --> 02:23:14,000

bill mcgonicle asks ramanujan said that

3071

02:23:19,429 --> 02:23:16,000

he learned from his goddess

3072

02:23:20,630 --> 02:23:19,439

others suggest well ramona john said

3073

02:23:22,790 --> 02:23:20,640

that he learned from his goddess by

3074

02:23:24,950 --> 02:23:22,800

meditating and praying or came to him in

3075

02:23:28,309 --> 02:23:24,960

dreams some of his

3076

02:23:33,190 --> 02:23:28,319

formulas esoteric formulas what does

3077

02:23:38,469 --> 02:23:36,230

can speak from ramanu for ramanujan

3078

02:23:39,990 --> 02:23:38,479

i tend to be a

3079

02:23:40,950 --> 02:23:40,000

rationalist

3080

02:23:42,389 --> 02:23:40,960

uh

3081

02:23:43,349 --> 02:23:42,399

atheist

3082

02:23:46,870 --> 02:23:43,359

uh

3083

02:23:52,230 --> 02:23:49,270

if i think hard about something i either

3084

02:23:55,670 --> 02:23:52,240

solve it or don't but there's there's no

3085

02:23:57,670 --> 02:23:55,680

there are no miracles in business

3086

02:23:59,750 --> 02:23:57,680

another question this one this is my

3087

02:24:03,030 --> 02:23:59,760

question are there some relatively

3088

02:24:05,990 --> 02:24:03,040

elementary concepts that you've recently

3089

02:24:07,030 --> 02:24:06,000

had a new insight on so for example my i

3090

02:24:09,990 --> 02:24:07,040

don't know if you know my brother

3091

02:24:13,750 --> 02:24:10,000

sebastian he's a professor at u of t as

3092

02:24:15,750 --> 02:24:13,760

well in math finance he was telling me

3093

02:24:17,990 --> 02:24:15,760

kurt you know only recently maybe last

3094

02:24:20,469 --> 02:24:18,000

year i thought i realized oh the

3095

02:24:22,230 --> 02:24:20,479

triangle inequality is actually about a

3096

02:24:24,230 --> 02:24:22,240

triangle he would only just use the

3097

02:24:26,389 --> 02:24:24,240

formula

3098

02:24:28,309 --> 02:24:26,399

also recently okay the jacobian

3099

02:24:29,670 --> 02:24:28,319

determinant the jacobian is actually

3100

02:24:33,910 --> 02:24:29,680

like

3101

02:24:34,950 --> 02:24:33,920

that point

3102

02:24:37,030 --> 02:24:34,960

doing

3103

02:24:38,710 --> 02:24:37,040

close instead of just okay think of it

3104

02:24:40,550 --> 02:24:38,720

as an abstraction of slopes and stuff

3105

02:24:42,469 --> 02:24:40,560

yeah so do you have an example

3106

02:24:44,630 --> 02:24:42,479

sorry of what of things that i've only

3107

02:24:46,230 --> 02:24:44,640

recently understood no no no of

3108

02:24:48,070 --> 02:24:46,240

something you have understood you've

3109

02:24:49,510 --> 02:24:48,080

used before but then maybe you've come

3110

02:24:51,510 --> 02:24:49,520

to a different understanding of you and

3111

02:24:52,790 --> 02:24:51,520

you say oh that's an interesting way of

3112

02:24:54,790 --> 02:24:52,800

thinking about it i didn't see that

3113

02:24:57,510 --> 02:24:54,800

before

3114

02:24:58,950 --> 02:24:57,520

it happens all the time well i wish it

3115

02:25:01,429 --> 02:24:58,960

would have happened all the times when

3116

02:25:03,030 --> 02:25:01,439

it happens it's a great day not all day

3117

02:25:04,790 --> 02:25:03,040

is a great day but there is the

3118

02:25:05,910 --> 02:25:04,800

occasional great day

3119

02:25:07,990 --> 02:25:05,920

uh

3120

02:25:14,710 --> 02:25:08,000

you know every time you learn some

3121

02:25:20,469 --> 02:25:17,750

a higher meaning it's it's or more

3122

02:25:22,389 --> 02:25:20,479

meaning than you thought it's great news

3123

02:25:25,190 --> 02:25:22,399

it happens all the time in the life in

3124

02:25:27,110 --> 02:25:25,200

the professional life of a

3125

02:25:28,630 --> 02:25:27,120

scientist

3126  
02:25:32,010 --> 02:25:28,640  
though not every day

3127  
02:25:32,020 --> 02:25:35,830  
[Music]

3128  
02:25:39,349 --> 02:25:37,110  
well

3129  
02:25:41,590 --> 02:25:39,359  
uh

3130  
02:25:43,990 --> 02:25:41,600  
i'll give you an example which somehow

3131  
02:25:47,110 --> 02:25:44,000  
which i think also partially involves

3132  
02:25:50,469 --> 02:25:47,120  
you so um

3133  
02:25:53,270 --> 02:25:50,479  
a few years ago i was asked to give a

3134  
02:25:56,070 --> 02:25:53,280  
10 minutes talk or something

3135  
02:25:57,830 --> 02:25:56,080  
uh to a i'm

3136  
02:25:59,349 --> 02:25:57,840  
i don't even remember what was the event

3137  
02:26:00,950 --> 02:25:59,359  
but you were there

3138  
02:26:03,670 --> 02:26:00,960

oh you remember that

3139

02:26:05,349 --> 02:26:03,680

mentorship event or something like that

3140

02:26:07,590 --> 02:26:05,359

i don't remember that's what that was

3141

02:26:09,750 --> 02:26:07,600

that's right and i thought what would i

3142

02:26:11,750 --> 02:26:09,760

talk about and i

3143

02:26:14,150 --> 02:26:11,760

well okay the truth is that i have some

3144

02:26:16,870 --> 02:26:14,160

list of uh

3145

02:26:17,910 --> 02:26:16,880

ready-made topics that i can talk about

3146

02:26:19,990 --> 02:26:17,920

you know

3147

02:26:22,550 --> 02:26:20,000

if you ask me to talk in front of high

3148

02:26:25,590 --> 02:26:22,560

school students i sort of have a number

3149

02:26:28,550 --> 02:26:25,600

of topics that are ready okay

3150

02:26:31,030 --> 02:26:28,560

uh but nothing really fit

3151

02:26:33,030 --> 02:26:31,040

and also sometimes i i get bored of

3152

02:26:35,670 --> 02:26:33,040

myself

3153

02:26:37,670 --> 02:26:35,680

so i have to occasionally add something

3154

02:26:40,710 --> 02:26:37,680

so i said okay why don't i talk about a

3155

02:26:43,110 --> 02:26:40,720

prisoner's dilemma

3156

02:26:45,910 --> 02:26:43,120

and um

3157

02:26:48,550 --> 02:26:45,920

so i i mentioned the prisoner's dilemma

3158

02:26:51,110 --> 02:26:48,560

in five minutes or so

3159

02:26:53,830 --> 02:26:51,120

and it's a very light map right it's

3160

02:26:56,230 --> 02:26:53,840

hardly math it's so light that it's

3161

02:26:58,950 --> 02:26:56,240

hardly math

3162

02:27:00,309 --> 02:26:58,960

but then i realized that it's that it

3163

02:27:03,190 --> 02:27:00,319

has a

3164

02:27:04,950 --> 02:27:03,200

profound i i guess the economists have

3165

02:27:07,270 --> 02:27:04,960

always understood that

3166

02:27:09,910 --> 02:27:07,280

they always thought it was important but

3167

02:27:12,309 --> 02:27:09,920

i realized it only relatively recently

3168

02:27:13,590 --> 02:27:12,319

so that was what is it three four years

3169

02:27:16,550 --> 02:27:13,600

ago

3170

02:27:18,790 --> 02:27:16,560

uh i only then understood how

3171

02:27:21,670 --> 02:27:18,800

profoundly

3172

02:27:23,990 --> 02:27:21,680

important it is

3173

02:27:28,070 --> 02:27:25,030

you know

3174

02:27:30,469 --> 02:27:28,080

the prisoner's dilemma is some numerical

3175

02:27:34,790 --> 02:27:30,479

example

3176  
02:27:40,070 --> 02:27:36,150  
you have

3177  
02:27:42,469 --> 02:27:40,080  
two sides two people a and b

3178  
02:27:44,389 --> 02:27:42,479  
and they can choose whether to

3179  
02:27:48,150 --> 02:27:44,399  
cooperate or

3180  
02:27:51,190 --> 02:27:48,160  
betray each one chooses independently

3181  
02:27:53,990 --> 02:27:51,200  
whether to cooperate with the other or

3182  
02:27:57,830 --> 02:27:54,000  
betray the other

3183  
02:28:01,830 --> 02:27:57,840  
and if you look at the numbers

3184  
02:28:05,110 --> 02:28:01,840  
each one no matter what the other does

3185  
02:28:07,670 --> 02:28:05,120  
would prefer to betray

3186  
02:28:11,270 --> 02:28:07,680  
and as a result both of them would

3187  
02:28:17,510 --> 02:28:14,950  
and the overall outcome is worse to both

3188  
02:28:19,349 --> 02:28:17,520

of them again i'm not describing the

3189

02:28:20,710 --> 02:28:19,359

whole thing i'm not telling the numbers

3190

02:28:23,510 --> 02:28:20,720

i'm just saying

3191

02:28:26,950 --> 02:28:23,520

there is this situation where if each

3192

02:28:32,469 --> 02:28:26,960

one acts selfishly

3193

02:28:32,479 --> 02:28:35,190

and

3194

02:28:38,790 --> 02:28:36,389

well

3195

02:28:42,630 --> 02:28:38,800

it has huge philosophical implications

3196

02:28:43,590 --> 02:28:42,640

you know there is a whole a whole um

3197

02:28:46,070 --> 02:28:43,600

uh

3198

02:28:47,590 --> 02:28:46,080

political class

3199

02:28:49,910 --> 02:28:47,600

that believes

3200

02:28:52,630 --> 02:28:49,920

that people should be acting selfishly

3201

02:28:55,750 --> 02:28:52,640

because if each one acts selfishly it's

3202

02:28:56,710 --> 02:28:55,760

actually for the best of the

3203

02:28:57,590 --> 02:28:56,720

uh

3204

02:29:01,670 --> 02:28:57,600

for

3205

02:29:05,190 --> 02:29:01,680

that's somehow the foundation of the

3206

02:29:06,870 --> 02:29:05,200

belief in free markets

3207

02:29:09,349 --> 02:29:06,880

uh so

3208

02:29:12,710 --> 02:29:09,359

uh uh

3209

02:29:15,110 --> 02:29:12,720

so so yes i am actually still a great

3210

02:29:17,510 --> 02:29:15,120

believer in free markets

3211

02:29:19,910 --> 02:29:17,520

i actually still greatly believe that

3212

02:29:22,950 --> 02:29:19,920

free markets are a good thing

3213

02:29:24,790 --> 02:29:22,960

but there is a little asterisk

3214

02:29:28,389 --> 02:29:24,800

sorry that's not duality that's an

3215

02:29:31,590 --> 02:29:28,399

asterisk so there is a little asterisk

3216

02:29:34,950 --> 02:29:31,600

asterisk and the asterisk says

3217

02:29:38,870 --> 02:29:34,960

provided somebody arranges so that free

3218

02:29:41,429 --> 02:29:38,880

markets when each one acts selfishly

3219

02:29:42,550 --> 02:29:41,439

you will not be led into prisoners

3220

02:29:47,349 --> 02:29:42,560

dilemma

3221

02:29:48,830 --> 02:29:47,359

you will be you'll be you'll stay out

3222

02:29:54,550 --> 02:29:48,840

and

3223

02:29:57,670 --> 02:29:54,560

benefit

3224

02:30:02,790 --> 02:29:57,680

the overall good so i mean this asterisk

3225

02:30:07,670 --> 02:30:05,270

ah sorry i well okay yes yes yes i get

3226

02:30:10,230 --> 02:30:07,680

it anyway uh

3227

02:30:11,990 --> 02:30:10,240

and you think it's a small asterisk but

3228

02:30:14,550 --> 02:30:12,000

the more you think about it you realize

3229

02:30:18,309 --> 02:30:14,560

it's actually a huge asterisk

3230

02:30:20,950 --> 02:30:18,319

it completely changes the picture

3231

02:30:23,910 --> 02:30:20,960

and it's much much much more common

3232

02:30:25,349 --> 02:30:23,920

you think of it as an esoteric example

3233

02:30:26,790 --> 02:30:25,359

but then you realize that it's

3234

02:30:28,790 --> 02:30:26,800

everywhere

3235

02:30:30,469 --> 02:30:28,800

so it's actually a very very big

3236

02:30:31,349 --> 02:30:30,479

asterisk

3237

02:30:32,550 --> 02:30:31,359

and

3238

02:30:35,349 --> 02:30:32,560

um

3239

02:30:36,710 --> 02:30:35,359

i think i realized it relatively

3240

02:30:38,469 --> 02:30:36,720

recently

3241

02:30:40,230 --> 02:30:38,479

i'm honored that you remember that i

3242

02:30:42,150 --> 02:30:40,240

didn't think that uh i'm honored to even

3243

02:30:44,710 --> 02:30:42,160

be a footnote in your memory

3244

02:30:45,750 --> 02:30:44,720

oh don't be silly

3245

02:30:48,150 --> 02:30:45,760

okay

3246

02:30:51,910 --> 02:30:48,160

what have you applied also this question

3247

02:30:55,590 --> 02:30:51,920

comes from harinav harinavis harinivis

3248

02:30:58,389 --> 02:30:55,600

sorry harinivis p asks has drawer

3249

02:31:02,150 --> 02:30:58,399

applied the principles of mathematics to

3250

02:31:08,710 --> 02:31:03,670

like let's give an example of a

3251

02:31:12,950 --> 02:31:10,630

well okay i mean

3252

02:31:15,830 --> 02:31:12,960

i can give two answers okay

3253

02:31:17,830 --> 02:31:15,840

one answer is uh well i don't know if

3254

02:31:19,110 --> 02:31:17,840

it's the principles of mathematics but

3255

02:31:20,870 --> 02:31:19,120

you know

3256

02:31:27,670 --> 02:31:20,880

uh

3257

02:31:29,270 --> 02:31:27,680

there was a claim going on and it's been

3258

02:31:31,190 --> 02:31:29,280

going around and in fact it's still

3259

02:31:33,429 --> 02:31:31,200

going around

3260

02:31:36,950 --> 02:31:33,439

uh that uh

3261

02:31:38,550 --> 02:31:36,960

you that the bible contains predictions

3262

02:31:41,030 --> 02:31:38,560

in code

3263

02:31:45,190 --> 02:31:41,040

so if you read the bible with letter

3264

02:31:49,429 --> 02:31:45,200

skips if you read every tenth letter

3265

02:31:51,510 --> 02:31:49,439

you will occasionally find a word

3266

02:31:55,349 --> 02:31:51,520

that's not surprising

3267

02:31:57,349 --> 02:31:55,359

but the claim was that these words

3268

02:32:00,389 --> 02:31:57,359

where

3269

02:32:01,990 --> 02:32:00,399

that that it actually happens more than

3270

02:32:04,950 --> 02:32:02,000

statistics would

3271

02:32:07,830 --> 02:32:04,960

uh predict and that these words have

3272

02:32:09,429 --> 02:32:07,840

messages in them

3273

02:32:13,590 --> 02:32:09,439

and uh

3274

02:32:15,270 --> 02:32:13,600

and there was a group of people in

3275

02:32:16,150 --> 02:32:15,280

jerusalem

3276

02:32:18,230 --> 02:32:16,160

that

3277

02:32:19,830 --> 02:32:18,240

published a paper and in fact it passed

3278

02:32:24,150 --> 02:32:19,840

peer review

3279

02:32:26,230 --> 02:32:24,160

uh but so so they published a paper

3280

02:32:27,190 --> 02:32:26,240

in which they

3281

02:32:29,670 --> 02:32:27,200

uh

3282

02:32:32,630 --> 02:32:29,680

supposedly proved this fact

3283

02:32:34,790 --> 02:32:32,640

they did careful statistical analysis

3284

02:32:36,150 --> 02:32:34,800

again carefully in quotes

3285

02:32:39,030 --> 02:32:36,160

uh

3286

02:32:40,870 --> 02:32:39,040

and and and and and showed that the

3287

02:32:42,550 --> 02:32:40,880

effect was real

3288

02:32:45,349 --> 02:32:42,560

and therefore

3289

02:32:46,469 --> 02:32:45,359

the bible uh must have been written by

3290

02:32:48,950 --> 02:32:46,479

god

3291

02:32:51,349 --> 02:32:48,960

because no human could have put this

3292

02:32:53,510 --> 02:32:51,359

information into the bible

3293

02:32:55,590 --> 02:32:53,520

it's information information that was

3294

02:32:57,910 --> 02:32:55,600

not did not even exist at the time that

3295

02:33:00,710 --> 02:32:57,920

the bible was written

3296

02:33:02,230 --> 02:33:00,720

and therefore in prayer and so so god

3297

02:33:03,429 --> 02:33:02,240

wrote the bible

3298

02:33:10,070 --> 02:33:03,439

uh

3299

02:33:12,710 --> 02:33:10,080

there is a god and that god loves hebrew

3300

02:33:14,710 --> 02:33:12,720

more than she loves japanese i

3301  
02:33:17,990 --> 02:33:14,720  
understand yeah uh you know this would

3302  
02:33:19,590 --> 02:33:18,000  
be the greatest discovery in if it was

3303  
02:33:21,590 --> 02:33:19,600  
true it would have been the greatest

3304  
02:33:23,349 --> 02:33:21,600  
discovery in the history of science and

3305  
02:33:25,190 --> 02:33:23,359  
i'm not kidding

3306  
02:33:28,389 --> 02:33:25,200  
right i mean there's no longer an

3307  
02:33:30,230 --> 02:33:28,399  
argument between atheism and tazin

3308  
02:33:33,030 --> 02:33:30,240  
pays and wins

3309  
02:33:35,429 --> 02:33:33,040  
my role was to debunk this

3310  
02:33:38,950 --> 02:33:35,439  
is this real life or not

3311  
02:33:42,630 --> 02:33:38,960  
i don't know i me and a group of people

3312  
02:33:44,469 --> 02:33:42,640  
read critically these assertions that go

3313  
02:33:45,670 --> 02:33:44,479

that were good enough that they passed

3314

02:33:48,630 --> 02:33:45,680

peer review

3315

02:33:50,309 --> 02:33:48,640

in a respectable journal and we found

3316

02:33:55,030 --> 02:33:50,319

gaps

3317

02:33:57,750 --> 02:33:55,040

that the same peer-reviewed journal

3318

02:34:00,630 --> 02:33:57,760

accepted our paper too

3319

02:34:02,950 --> 02:34:00,640

okay so you know in some sense my role

3320

02:34:04,950 --> 02:34:02,960

was negative right what could have been

3321

02:34:07,670 --> 02:34:04,960

the greatest discovery in the history of

3322

02:34:09,910 --> 02:34:07,680

science a proof that there is god and

3323

02:34:10,790 --> 02:34:09,920

it's the hebrew god

3324

02:34:13,030 --> 02:34:10,800

uh

3325

02:34:14,870 --> 02:34:13,040

was debunked maybe it's a negative

3326

02:34:17,590 --> 02:34:14,880

discovery but

3327

02:34:19,590 --> 02:34:17,600

well i mean even maybe my effect well my

3328

02:34:22,469 --> 02:34:19,600

part was negative i've killed a great

3329

02:34:26,870 --> 02:34:22,479

discovery but that's also a

3330

02:34:30,870 --> 02:34:26,880

a valuable thing to do i mean to kill a

3331

02:34:32,790 --> 02:34:30,880

uh the other thing is uh

3332

02:34:36,710 --> 02:34:32,800

otherwise

3333

02:34:39,349 --> 02:34:36,720

mathematics plays an extremely limited

3334

02:34:41,910 --> 02:34:39,359

role in my life

3335

02:34:44,389 --> 02:34:41,920

other than my professional life if you

3336

02:34:46,950 --> 02:34:44,399

ex if you cut out

3337

02:34:48,950 --> 02:34:46,960

uh the eight hours a day that i work on

3338

02:34:51,510 --> 02:34:48,960

mathematics mathematics has no role in

3339

02:34:54,309 --> 02:34:51,520

my life or hardly any role so i mean you

3340

02:34:56,710 --> 02:34:54,319

do and in fact also almost no role in

3341

02:35:00,389 --> 02:34:56,720

your life so basically

3342

02:35:03,830 --> 02:35:00,399

you know if you um

3343

02:35:07,030 --> 02:35:03,840

you give change in restaurants you uh so

3344

02:35:08,309 --> 02:35:07,040

so or in when shops sorry you add 15

3345

02:35:09,830 --> 02:35:08,319

percent

3346

02:35:11,670 --> 02:35:09,840

tip

3347

02:35:12,750 --> 02:35:11,680

that's about the math you need in real

3348

02:35:16,389 --> 02:35:12,760

life

3349

02:35:18,950 --> 02:35:16,399

multiplication you don't need

3350

02:35:22,950 --> 02:35:21,910

but if you're a carpenter you probably

3351

02:35:25,270 --> 02:35:22,960

need it

3352

02:35:27,750 --> 02:35:25,280

right you need to

3353

02:35:30,710 --> 02:35:27,760

tiles or you know if you're a trade

3354

02:35:33,429 --> 02:35:30,720

person you need to tile a certain room

3355

02:35:36,070 --> 02:35:33,439

this the room is five by six right how

3356

02:35:38,469 --> 02:35:36,080

many tiles do you need so multiplication

3357

02:35:41,030 --> 02:35:38,479

trade people need but but but but people

3358

02:35:41,870 --> 02:35:41,040

like me don't need

3359

02:35:45,190 --> 02:35:41,880

um

3360

02:35:48,550 --> 02:35:45,200

trigonometry well maybe architect nitric

3361

02:35:51,190 --> 02:35:48,560

architecture trigonometry some parts of

3362

02:35:52,630 --> 02:35:51,200

engineering and we get more and more

3363

02:35:54,710 --> 02:35:52,640

esoteric

3364

02:35:56,790 --> 02:35:54,720

need higher and higher mathematics

3365

02:35:59,750 --> 02:35:56,800

without the very high mathematics

3366

02:36:02,469 --> 02:35:59,760

without general relativity

3367

02:36:05,030 --> 02:36:02,479

gps satellites wouldn't work so in some

3368

02:36:07,270 --> 02:36:05,040

sense we use mathematics every day

3369

02:36:09,670 --> 02:36:07,280

but we're not the engineers who design

3370

02:36:12,870 --> 02:36:09,680

gps city live seat satellites gps

3371

02:36:14,950 --> 02:36:12,880

satellites were designed by a group of

3372

02:36:16,710 --> 02:36:14,960

a very small group of people somewhere

3373

02:36:17,750 --> 02:36:16,720

in some

3374

02:36:19,750 --> 02:36:17,760

you know

3375

02:36:22,070 --> 02:36:19,760

design bureau

3376  
02:36:25,190 --> 02:36:22,080  
and they use high-level mathematics so

3377  
02:36:27,670 --> 02:36:25,200  
so so but my real life

3378  
02:36:29,349 --> 02:36:27,680  
high level mathematics

3379  
02:36:32,070 --> 02:36:29,359  
is almost nothing

3380  
02:36:34,309 --> 02:36:32,080  
except once sorry the bible codes and

3381  
02:36:37,670 --> 02:36:34,319  
another time

3382  
02:36:42,150 --> 02:36:37,680  
and i've given talks with this title

3383  
02:36:44,309 --> 02:36:42,160  
so uh the title was uh the

3384  
02:36:45,429 --> 02:36:44,319  
hardest

3385  
02:36:54,230 --> 02:36:45,439  
uh

3386  
02:36:56,309 --> 02:36:54,240  
ever

3387  
02:36:57,190 --> 02:36:56,319  
really

3388  
02:36:59,670 --> 02:36:57,200

yeah

3389

02:37:02,150 --> 02:36:59,680

and if you google this title probably

3390

02:37:02,950 --> 02:37:02,160

you'll be able to find a video of that

3391

02:37:05,670 --> 02:37:02,960

talk

3392

02:37:07,990 --> 02:37:05,680

and you'll find that one time

3393

02:37:10,469 --> 02:37:08,000

where

3394

02:37:13,110 --> 02:37:10,479

it was actually in my professional life

3395

02:37:15,910 --> 02:37:13,120

but in a meta way

3396

02:37:18,389 --> 02:37:15,920

so not my research but something about

3397

02:37:21,110 --> 02:37:18,399

how to present my research i ended up

3398

02:37:23,990 --> 02:37:21,120

using a very high level mathematics

3399

02:37:26,550 --> 02:37:24,000

hyperbolic geometry in fact

3400

02:37:29,190 --> 02:37:26,560

so one time it happened anyway what was

3401

02:37:33,030 --> 02:37:29,200

your next question

3402

02:37:35,110 --> 02:37:33,040

why does it take 360 pages of abstruse

3403

02:37:36,469 --> 02:37:35,120

symbols to prove that one plus one

3404

02:37:38,550 --> 02:37:36,479

equals two

3405

02:37:40,790 --> 02:37:38,560

occam's razor says we can cut this we

3406

02:37:42,550 --> 02:37:40,800

can just say one plus one equals two

3407

02:37:44,070 --> 02:37:42,560

because every single last one of us

3408

02:37:46,150 --> 02:37:44,080

believes it does

3409

02:37:47,750 --> 02:37:46,160

so what do you make of that why is it so

3410

02:37:50,070 --> 02:37:47,760

complex to prove something simple like

3411

02:37:51,110 --> 02:37:50,080

one plus one equals two do we even need

3412

02:38:02,630 --> 02:37:51,120

that

3413

02:38:07,429 --> 02:38:03,990

so

3414

02:38:12,830 --> 02:38:09,030

let me answer the

3415

02:38:16,469 --> 02:38:12,840

let me answer a different question

3416

02:38:19,510 --> 02:38:16,479

uh you know so one plus one equals two

3417

02:38:21,910 --> 02:38:19,520

so the the reference is probably to uh

3418

02:38:24,790 --> 02:38:21,920

work of uh russell

3419

02:38:24,800 --> 02:38:29,990

basically

3420

02:38:36,550 --> 02:38:32,950

if your axiom system is

3421

02:38:37,990 --> 02:38:36,560

very very very basic

3422

02:38:40,469 --> 02:38:38,000

and

3423

02:38:45,349 --> 02:38:40,479

um

3424

02:38:49,590 --> 02:38:47,030

primitive in a way very very

3425

02:38:52,150 --> 02:38:49,600

simple-minded and you want your axiom

3426

02:38:55,190 --> 02:38:52,160

system to be very very very basic

3427

02:38:58,469 --> 02:38:55,200

then it might be that even proving one

3428

02:39:01,349 --> 02:38:58,479

plus one equal to would be difficult

3429

02:39:03,670 --> 02:39:01,359

but it will be a part of the build up

3430

02:39:07,830 --> 02:39:03,680

and later you will be uh

3431

02:39:13,510 --> 02:39:10,870

but the truth is it's silly okay but let

3432

02:39:15,349 --> 02:39:13,520

me give you an another example okay so

3433

02:39:17,190 --> 02:39:15,359

uh you know there is the intermediate

3434

02:39:22,150 --> 02:39:17,200

value theorem

3435

02:39:25,349 --> 02:39:22,160

that if you have a function

3436

02:39:26,550 --> 02:39:25,359

continuous function so if  $f$  is

3437

02:39:30,389 --> 02:39:26,560

continuous

3438

02:39:35,270 --> 02:39:30,399

and it's negative here and positive here

3439

02:39:41,190 --> 02:39:38,550

uh we teach it in week seven

3440

02:39:43,270 --> 02:39:41,200

maybe i don't know of undergraduate

3441

02:39:45,270 --> 02:39:43,280

calculus maybe it's just week five or

3442

02:39:46,469 --> 02:39:45,280

maybe it's week nine i don't remember

3443

02:39:47,750 --> 02:39:46,479

okay

3444

02:39:50,150 --> 02:39:47,760

you can ask

3445

02:39:50,950 --> 02:39:50,160

this is so idiotic

3446

02:39:52,469 --> 02:39:50,960

right

3447

02:39:58,230 --> 02:39:52,479

why

3448

02:40:00,950 --> 02:39:58,240

prove the obvious that if you go

3449

02:40:04,070 --> 02:40:00,960

continuously from here to here you'll be

3450

02:40:09,990 --> 02:40:07,030

and the answer

3451  
02:40:12,150 --> 02:40:10,000  
is that when you prove the intermediate

3452  
02:40:14,790 --> 02:40:12,160  
value theorem

3453  
02:40:16,950 --> 02:40:14,800  
you are not actually proving the

3454  
02:40:20,230 --> 02:40:16,960  
intermediate value theorem

3455  
02:40:23,429 --> 02:40:20,240  
you are actually testing

3456  
02:40:25,030 --> 02:40:23,439  
your definition of continuity

3457  
02:40:27,750 --> 02:40:25,040  
you're testing

3458  
02:40:33,110 --> 02:40:27,760  
your abstract setup

3459  
02:40:35,110 --> 02:40:33,120  
your language you're testing

3460  
02:40:38,230 --> 02:40:35,120  
uh

3461  
02:40:40,790 --> 02:40:38,240  
you know the the machinery of for every

3462  
02:40:43,750 --> 02:40:40,800  
epsilon there exists a delta such that

3463  
02:40:46,790 --> 02:40:43,760

blah blah blah if you could not prove

3464

02:40:50,469 --> 02:40:46,800

the intermediate value theorem

3465

02:40:53,110 --> 02:40:50,479

you'd be rejecting the abstract system

3466

02:40:56,710 --> 02:40:53,120

not the intermediate value theorem you'd

3467

02:40:57,590 --> 02:40:56,720

be rejecting this not that

3468

02:40:59,590 --> 02:40:57,600

so

3469

02:41:01,910 --> 02:40:59,600

the seven weeks were not about the

3470

02:41:03,030 --> 02:41:01,920

intermediate value theorem they were

3471

02:41:05,750 --> 02:41:03,040

about

3472

02:41:08,469 --> 02:41:05,760

this for every epsilon there exists

3473

02:41:10,870 --> 02:41:08,479

delta and then you can ask

3474

02:41:13,510 --> 02:41:10,880

what's for every epsilon there exists

3475

02:41:15,110 --> 02:41:13,520

delta for why do we need this well we

3476

02:41:17,110 --> 02:41:15,120

don't need it to prove the intermediate

3477

02:41:19,030 --> 02:41:17,120

value theorem the intermediate value

3478

02:41:21,030 --> 02:41:19,040

theorem was testing this

3479

02:41:23,670 --> 02:41:21,040

what do we need it for

3480

02:41:24,710 --> 02:41:23,680

and the answer is well there are later

3481

02:41:25,670 --> 02:41:24,720

things

3482

02:41:29,349 --> 02:41:25,680

like

3483

02:41:33,510 --> 02:41:29,359

uh e to the x is equal to sum of x to

3484

02:41:35,750 --> 02:41:33,520

the n divided by n factorial

3485

02:41:37,429 --> 02:41:35,760

which is this by the way looks innocent

3486

02:41:39,670 --> 02:41:37,439

and people think they understand it but

3487

02:41:42,230 --> 02:41:39,680

it's actually a miracle

3488

02:41:43,910 --> 02:41:42,240

and this miracle depends on well it

3489

02:41:46,389 --> 02:41:43,920

doesn't depend but i mean there are

3490

02:41:48,469 --> 02:41:46,399

maybe other ways to reach there but but

3491

02:41:50,550 --> 02:41:48,479

but you you will believe this miracle

3492

02:41:52,710 --> 02:41:50,560

miracle after you've understood this

3493

02:41:53,510 --> 02:41:52,720

system

3494

02:41:58,389 --> 02:41:53,520

so

3495

02:41:59,429 --> 02:41:58,399

didn't go from

3496

02:42:03,190 --> 02:41:59,439

uh

3497

02:42:04,870 --> 02:42:03,200

here to here

3498

02:42:07,590 --> 02:42:04,880

to here

3499

02:42:10,790 --> 02:42:07,600

but more like this was known it

3500

02:42:14,150 --> 02:42:10,800

validated this and then uh we could use

3501

02:42:17,830 --> 02:42:16,150

the podcast is now finished if you'd

3502

02:42:21,030 --> 02:42:17,840

like to support conversations like this

3503

02:42:25,110 --> 02:42:21,040

then do consider going to [patreon.com](https://patreon.com)

3504

02:42:27,750 --> 02:42:25,120

c-u-r-t j-a-i-m-u-n-g-a-l

3505

02:42:29,510 --> 02:42:27,760

that is kurt jaimungle it's support from

3506

02:42:31,349 --> 02:42:29,520

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