Introduction to Quantitative Research Methods

Good morning everyone. Okay, this is II2202 (as you all expect), and the lecture for this morning is an introduction to quantitative research methods. So, those of you who are not in section D, you will now -- I will introduce myself anyway - my name is Mark [Smith], I'm a professor here at the School of ICT in Kista and my own study area is in the of development of IT products. So, because of that and because of my history and background Iäm going to talk to you about doing the studies of the writing reports and doing methodology with respect to quantitative - quantitative studies. So, that is going to be the topic for today. Now one thing. I come from industry myself.

I have been at KTH for about ten years. But before that, I was in industry in Silicon Valley for double that amount of time - over twenty years. So, a lot of what I am going to tell you has very much an applied job-focused bent to it, about how to be able to exploit scientific writing and experimental design for when you are going to be going out in the industry. So, you are going to see that bias in there. Well, the other thing is because I come from industry, this idea of somebody standing up in front of all you guys and lecturing like this - Agh! They don't do that in industry. So, in other words, more of a discussion. If I say something and you want to add to it or ask a question, or you say, “what the heck is he saying”, just stop me and yell out a question. That would be great! Or a comment. Because that is the way we do it in industry, we don't wait until the end of the meeting to ask a question. So, please feel free to make comments and other kinds of questions or if I use a word - sometimes I use slang - what does that means, stop me and ask. Okay, so what is this whole thing about quantitative research methods, and you are you going to want to know that depending upon the kind of project you are doing. What does it really mean, and why is it important at all? And I mentioned that I'm from industry. Why does industry care? After all, we want to make products, and we want to make money. Was has that got to do with scientific writing?

Slide 2: What is important for industry? (besides your technical skills)

Okay, well, here's a little bit of evidence of what it's got to do with scientific writing - I've got here a slide from an organization that works with KTH called iCES - what this is - is the innovative center for embedded systems. It is an industry group. And they actually gave a presentation to embedded systems students not to long ago. And they put up these things called what's important in the industry. So, if you think you are going out into industry, if you think you are going to be starting a company, or you think you are going to be working for a major time employer, these guys sort of have an idea what's going to be important to you. So, they said sure, of course. You have got to be able to communicate. Language skills are good. We are in Sweden, so, of course, the Swedish part and English certainly, any other language that is used to communicate with your customers with your colleagues. You have got to be able to communicate, but there are other things too. Innovation – you have got a

mindset that looks to be able to provision the environment you are in to be able to innovate. That has a lot to do with scientific methods. And networking and by networking, they don't mean do you have the right kind of you sort of Ethernet cables running through your room. What they really mean is do you interact with people are you comfortable with people. Can you go up to talk to people and say, "Hey, let's work on a project". It's got to go a little bit beyond, you know, Facebook. You need some real friends that is networking. And then finally, curiosity - do you look at the world around you and say where the problems that I can solve? What can I contribute? That is what it is you want to seek. In other words, they don't want to look at things out there that have to do with commerce as problems; they want you to convert them into opportunities. So, that is a big deal.

Slide 3: What is important for industry? (besides your technical skills)

Now, with respect to scientific writing - documentation presentation, that has everything to do with what we're doing in here. You have got to be able to document, you have got to clearly say what you are designing. If you are a technologist or marketing person or a salesperson - if you can't communicate what it is that you are designing, which is what is that the market opportunity is, what it is that your customers want - well then, forget it – you are not doing to make any profit. So that is why this course is important. How do you do that? How do you do that in a way that persuades? How you do that in a way that negotiates? How do you do that in a way to convince your boss that you are doing the right thing? Aaaah! Presentations are the same thing. If you can communicate by writing a report, you have got to be able to present it as well. So that is why in this class, we have got those seminars and stuff where you have got to get up in front of the room. And then, of course, social skills and team project work. You don't work alone. _No_ successful person works alone. So, develop those skills. That helps in this class as well. Work with people you don't know. Mix your skills with the person sitting next to you has. That is important. So, this also gives you an opportunity to work on those things. But that is why it's important. Industry _wants_ what this course is talking about, and that is one of the reasons why we give it.

Slide 4: Quantitative Research Methods

Okay, let's jump into quantitative research methods. Now, I'm going to do a little bit of comparing of qualitative one, but that is covered in a different lecture. I'm mostly going to focus on qualitative methods, and I want to really define about what they mean. What is the difference? How can you choose? Because no one method is completely right - you have to be supple you have got to be able to go from one method to another depending upon what it is you are trying to prove or what kind of an opportunity you are trying to show. So, when we talk about quantitative methods, what we're talking about is some kind of a study or method that deals with measurable data. Aaah! What does that mean? What it means is that its numbers or an amount that can be directly measured. Something that you can actually go into a piece of equipment or something that you can go and evaluate. How many trees are growing in this block? How many cigarettes a day you smoke? How many Volts from out of this piece of a circuit? Etc. And things like that. They have to have some sort of known units

of measurement. It can't be fuzzy. You have got to be able to communicate what is this number measured in. This is in Volts? Is that items? What? Is it current? Is it something else? But it has to have some unit of measurement. That also characterizes a quantitative study. They have to be that way - so that can make comparisons. You need to be able to compare the same things together - Volts compared to Volts means something. Volts compared to _red_ - doesn't. So, you have got to be able to have this basis in which to compare and evaluate. So they are numerically based. You are dealing directly with numbers - that is the quantitative part. And the results are based and judged on these data comparisons. Is something better? Well, the numbers will prove it. That is the strength of a quantitative study. So, these methods are used in a lot of different fields- Certainly, they are used in all STEM areas - Science, Technology, Engineering, and Math. But they are also used in economic areas, like finance. Certainly, financial planning, marketing - you want these methods, so they go across a whole lot of areas. It isn't just engineering or just mathematics or just physics. But the nice thing is that if you use quantitative methods and you use it properly, now you have got a real - a real tool to be able to convince people that what they're trying to tell them, what you are trying to sell them, what you are trying to show them, has meaning - real, measurable meaning. So, that is the real strength of doing a quantitative study.

Slide 5: Product evolution example from industry Note the quantitative nature of this

Now, here is one more slide from iCES, and you can see examples, the trends I am talking about. So, here is something where they say, that they're talking about product evolution and I worry a lot about product evolution in the fields that I'm in. But you can see what they're talking about. They are looking at IT devices in the past and are looking at where IT devices are going in the future. But notice how they are comparing them. They are not comparing them based on something that is fuzzy- you know- subjective; they are using numbers - they are using actual measurements here. So there are saying, "Ah! Performance" Performance with respect to what? Well, with respect to instructions per second or millions of pixels rendered or better battery life in terms of lower power - things like that. These are numbers with units you can actually compare. They are talking about price. Wow!

There is a quantitative amount. If I haven't convinced you that quantitative systems are good, think about _money_ being the ultimate sort of quantitative amount - when it comes to the fields that we are in. And finally, complexity, of course, how many components used in the system and all the subcomponents that come together, which are also based on performance, price, and other kinds of metrics. So, you can see it. And they say they're going from one to the others is innovation - that is their words. Aha! Going from these kinds of older devices to things like smartwatches and self-driving electric cars and stuff like that, it's all about innovation. Yep! It is! And that is where quantitative methods come into play; quantitative methods have everything to with innovation - today.

Slide 6: Quantitative Methods and Goals: We will talk about:

Okay, now what we're going to do is go on to the methods and goals. These are the things you want to be sure of as you design your study and to make sure you are doing the right thing. So, this is really what we want to talk about for quantitative methods and the goals of them. You want to look at the role of data in your scientific study. When you are thinking about a quantitative study: What is the data supposed to show? What is its role? You probably want to try to prove something - so you have to get that down. Another thing is planning. If you are going to do any kind of a study, you have got to plan. And certainly, that is true for quantitative studies. So, you have to know what kind of data you want and how much is enough. Very often, if you want to start making measurements (you know), what does it mean to go to some sort of a testbed and get one piece of data - one measurement? Well, it doesn't mean much as we're going to find out. Well, how much - how much is enough? Well, that is part of the magic, you have to know how much is enough - and we're going to look at that. Measure the data - that is also everything. If you are not measuring it properly, then the data is meaningless. Make sure you measure it in a way where it has meaning, and you can express what the meaning is. Well, get into all kinds of ways that you can do it right, but also very common ways that you will recognize for doing it wrong. And then, how do you express the significance of your data. This is the biggest area where you can have power. If you could express what your data means. Why is this data significant? What is the: "so what" about your data? And you should be able to do all of these things as an independent scientist or an employee or an entrepreneur or anything. So it covers every field. You can't get away from it. They are always going to have to deal with the numbers. So, that is really what we're going talk about. This is the introductory lecture about this, later on, there will be a much more detail about the nature of quantitative data and what you can do to it to make sure that it is accomplishing these things. Okay.

Slide 7; Quantitative and Qualitative methods: What's the difference?

Now, just to put it into perspective - so we are talking about quantitative methods - that is going to be talking about here - but on the other side of the course, there are qualitative methods. So, it's always good to really understand we're trying to get a feel for the difference - the major differences - between the two approaches. So we're going to look a little bit that. Now, one thing that I want to make really clear as we go through - what is the difference between a quantitative study and a qualitative study? The differences aren't that stark- some of them are- some of them really jump out at you. But in other cases, you are saying, "well maybe there's not a whole lot of difference between the two" Yeah. Be aware of that.

In some cases, you won't see a lot of differences between the two kinds of studies.

But in some cases, you will. Get a feel for it. Also, don't get the impression that one kind of study is better than the other. Generally, don't think in this class - Argh! I don't want to look at this project area or try to solve this kind of problem because it's not quantitative - because quantitative is better. No, I'm not trying to give you that impression. Quantitative is not always better. It has to do with the problem you are trying to solve or the question you are trying to answer. Choose the study that makes sense. They are both good. So, that is a - that

is a big deal. So, now what we are going to do - is start to look at some of these differences. And like it says up here - the differences can sometimes be kind of abstract.

Slide 8: Differences

So here are some one-liners. There are some summary slides later that are going to help with really showing the major differences. But here are some ways you can look at - these are suggestions - so in a quantitative study as we have already said, you are dealing with numbers. But in a qualitative study, you deal with words. In other words, descriptions.. Now numbers describe certainly, but words are a little bit more subjective. We don't always have a ready unit to be able to attach to a word. Say, for example: Is something good? What is the units of good? I don't know. Okay? But sometimes I can be very powerful because that is how humans think. Another one is in a quantitative study; it's about the researcher's actions - meaning if you are a researcher and you have got a quantitative study you have decided that this new battery technology that you have invented has better energy capacity and can last longer in a typical cellphone application. Alright. You, as the researcher, are going to go in there, and through your actions, you are going to you are going to get data you are going to measure, and you are going to process that data and show your results. In a qualitative study, it is often the participants' opinions. So, what you are going to do is say, for example, I ask a question: "Do the residents of Stockholm think that air quality is good?" How are you going to find that out? Well, you are going to have to go out, find the participants'' opinions.

Do you think the air quality is good? Ah! Yah! Well, it is OK unless you are standing behind one of those biodiesel busses. Right? This kind of a thing. So, you are really worried about that. In quantitative, there is the whole idea of theory testing. I have a theory; my battery technology is going to last longer. I'm going to test that theory. In a qualitative study is about theory regeneration. Is the air quality of Stockholm good? "I don't know - I donä't have a theory about it one way or another. But I'm going to go find out." and then generate a theory based on what I'm studying I can now theorize that the air quality is quite good - maybe. But I can claim it. That is typical of a qualitative study. Numerical based analysis in a quantitative study.

[Student asks:] Why would you base, or why would you test the air quality doing a qualitative study?

[Professor Smith] Because you are asking your participants. "Do you think it is good or bad?" Now, you could also do a quantitative [study].

[Student asks:] But what do you get out of it if they say it is good or not? does if add anything - I think you should just - it makes more sense to go quantitatively.

[Professor Smith] It might be a purely - Do I want to make a study based on what the human perception is.

[Student says:] And compare it to the quantitative?

[Professor Smith] And you can also compare it to the quantitative - exactly. You can also do that - and that would be a fascinating study. Right? On the one hand, you could do both - you can do a quantitative study that measures know parameters of air quality. And then, well- Do people who live here think that air quality is good. And that would be a fascinating study. So, aha! Right here is an example of you can do both. That is good. That is a good comment. Keep asking questions. That is good. So, numerical based analysis you have got a bunch of numbers, you are now going to stick them into some kind of number crunching system the statistical analysis thing, like R or something or maybe you will write a bunch of programs in python - and you will crunch your numbers and come up with results. The other one is a process-based analysis. Maybe it's not numerically based, maybe something where you are measuring and looking at variations of people's opinions. Or it is some kind of data science for you are looking for - for not obvious ways that data or responses are related to each other. There are lots of different kinds of tools to do that. So, in other words, quantitative stuff tends to be much more structured: get the data - put it into these kinds of data formats - subject it to these kinds of statistical tests. The qualitative is a little bit more unstructured. You can come up with different methods of looking at your data or determining what it means based on the source of it. Other things as well.

Slide 9: Differences

In quantitative, often people say, "that I want to explain something". I'm going to explain to you that my batteries last longer or are more efficient, or I am going to explain to you why my processor has better performance. Often in the qualitative, it's about understanding and the example we have over here, [I didn't pay them] is a great example is a good one to see this. On the one hand, in a quantitative study, I'm going to explain to you what is the particulate matter, what are the nitrogen compounds, what is the sulfur compounds, etcetera in the air in Stockholm that we breathe. So, you are going to get an explanation for air quality in that way. In a qualitative study where I asked people: "Do you feel that the air quality is good?" I can understand what people think - it's hard to understand how they view their living environment. So, that is a that is a good example of that comparison. With quantitative, I can predict I could say, "Based on this numerical data that I have seen. I can predict that the next generation of batteries is going to be this much better". A famous example is Moore's Law. Right! Every eighteen months, everything gets better - we can predict. In qualitative, it is interpretation. Aaah! People were telling me things that I can now interpret about air quality, quality of life, etc. In quantitative hard data measurements - okay. Versus soft data diversity - rich- in other words, in a quantitative study, I have decided what data I am going to get that it. That is what I am going to be limited to. Good hard numbers it out of my oscilloscope, data out of my voltmeter, data out of my power meter, whatever. On the other side, the data is going to be much more diverse - much more rich - people are going to explain to me what they feel or what they think. Or why they think that. And then, also I get an objective result in quantitative studies. If I am lucky and everything goes well, and the study is a success - well, the answer is X plus or minus some amount of variance, of course, but actually, it is a number. And if you run through the same process, you run through the same way of collecting data, hopefully you will get X too. It is objective

- there's not a lot of room for debate. We debate about the methods, but if you follow the same methods - you are going to get X- On the other side of the coin in qualitative - it is a subjective interpretation. Right. Is the air quality good? Well, you might have a different idea of what good is. You might have a different idea of what good is. If you were raised in the countryside where air really is pristine - well, you are probably going to have a lower tolerance for inter-city air. But if your kid that was brought up in the inner city air all your life - well, you are going to have a different way of looking at it. In order words, it is open to this subjective interpretation. Things can get kind of fun, actually, if you do a qualitative study and you have to deal with that. And then, finally, the environment. In quantitative, it tends to be closed, and you are going to do this in a lab. You are going to take this piece of equipment, or you are going to do something you are going to do it in a laboratory. The laboratory could be someplace way outside someplace. A laboratory in a forest, a laboratory in the inner city, a laboratory in a subway station - but it is still in a closed environment. Whereas in a qualitative study, often, it is done in a more natural setting because I really wanted to study something as it happens in nature. These are just again general characteristics. All of these characteristics are open to subjective debate, but they tend to characterize one or the other.

Slide 10: Overall Design for *Quantitative* Research

Okay, so how do you design for it. If you are going to choose. Well, if you are going to choose - really look at the nature of your problem and see how well they fit these design parameters. So, for example, and again - a lot of these are the same between the two - the two kinds of students. But this will help you decide do you take a qualitative or quantitative approach. So, the overall design guide for a quantitative approach is to look for drivers that influence or guide your research direction. What are your drivers? Are you drivers such that they are affecting physical quantities? Well, then they are probably going to be numeric or quantitative. Then look for research methods, strategies, and design. So, if your processes are such that they give way to experiments - where you are actually collecting hard data or case studies where you are actually looking at and counting, say, for example, how many packets of snus do you chew per day. Well, that is very qualitative. I can go and look at a case study and count the packets of snus. Things like that. Or surveys. Surveys, however, that collect real numbers - not subjective opinion. That is a good way of looking at a quantitative study. Then look at your data collection technique. This is also things like measurements, questionnaires, case studies - again; you are going to go out and look at the case and get data numerical data directly from them. Measurements are probably the most obvious. Just go in the lab and do it. Again questionnaires, you can use them- that is another way but make sure that it's bringing back numerical data, not opinion. And then, the data analysis is going to be statistical methods or data science - in other words, something based on numbers. You put the numbers in, and some kind of analysis or rendering of that raw data comes out. Quality assurance you have got to have that- ways of making sure that your data is valid. Make sure you take into account the ethics of your study. Not just the ethics of what you are doing, but also the ethics of the way that you have done it. Dependability, reproducibility, and transferability - so is it dependable are your methods recognized - are these good dependable

ways of measuring data? Is a reproducible can somebody else do it. And then transferable, do you have results that somebody else can use. Can I transfer my results to another study? Or they so abstract, you know, that people can only use it as a basis to think about. But if you can definitely transfer those numbers, then its probably a quantitative study. And then, the presentation of the results - written records, publications, demonstrations, etc.

Slide 11: Overall Design for *Qualitative* Research

Now compare these, and these will be on the slide summaries that you can download - to qualitative, you see there's a lot of similarities, but then there are differences in there, and the differences can be subtle. Still, when you want to think about the study - you still have the drivers that influence or guide research directions that is no different. In other words, you are looking for it to answer a question, solve a problem, discovered the reasons, or some kind of a mystery. It is the same sort of thing, so that is no different. However, the research methods, strategies, and designs are going to be different. You are going to look ethnography, it's got something to offer and has got something to do with people, populations, demographics. You still have case studies, but surveys, action research - now you are going to go out and do surveys - "Is the air quality good?", where good is definitely going to be a personal decision. Data collection techniques in a lot of it is the same: surveys, case studies, but just observation - just standing and watching people. In fact, that is one of my favorite ways of doing IT product development studies. I used to do a lot of that just the tunnelbana, and I am not collecting data, I'm just standing around watching people: What did they do with their IT devices? How are we using their IT devices? How are they interacting with others while they are using their IT devices? This is all definitely not numeric - it is very qualitative. You can discover a lot from doing those sorts of things. And then interview people and ask them why did you choose these things. Well, you are going to get all kinds of interesting impressions, but it won't be about quantitative nature; it will be qualitative in nature. But it's very valid. And then, the data analysis processes and procedures - well, again, you can use statistical methods of data science. Wait a minute - I'm using statistical methods in a qualitative study? Yes, you can. Which means there are ways to be able to take subjective data and turn it into something that can be analyzed through numerical means. That doesn't mean that you are going to get an objective answer. And it doesn't mean that you are always going to get the same answer - even if another researcher does exactly the same study. But it does mean that you can use well-established methods that are grounded in something that is valid. And then, finally, the quality assurance that is exactly the same: quality is quality. And that is something that at the very end of this lecture we will summarize because if you don't _do anything else_ in a course like this - understand the reasons to have high-quality - because if you have a lousy quality okay yeah maybe it will affect your grade here, but later on it will affect your career. You have to have high-quality in everything you do. with respect to scientific communication writing an experiment design-if the quality sucks - well, your boss is going to notice and you don't want that. And then, finally, the presentation of the results: written records, publications, demonstrations - those are exactly the same as well. You still are expected to teach; you still are expected to transfer what you know - whether it

is - it is quantitative or qualitative, and that has to be ultra-high-quality; otherwise, again, your boss and the public and your customers aren't going to buy it.

Slide 12: The ROLE of data, or what data is for (a possible quantitative example from real life)

All right. So, let me give you an example of what I mean- So I sort of mentioned that, you know, of don't do a high-quality job and doing these kinds of studies and doing these methodologies that you might get into trouble with the bosses or customers. Okay, so here is an example of what I mean by that. You are probably thinking, "Nah, why would my boss care" - "why would my customers care". Right now, I'm teaching; in addition to a section of II2202, I am also teaching RFID. So hi to all of you guys who are in my RFID class. But here is an example right out of that - so let's say that you are a technologist working for a big company - actually let's say you are working for TagMaster down the street here in Kista and let's say that you have been given a job to design the following: You have got to design a system where customers pay for parking - okay - and they're going to pay for it at a machine that uses an RFID tag. So RFID tag means RFID - radio frequency identification, and it is used a lot now. And payment is a big deal. And a lot of you are probably carrying multiple RFID devices. So, Oh! Okay! That is your job. And it says here that the way it's used is that the RFID tag will active a gate that lets them leave after they pay. So they park for some amount of time and then when they're leaving they got (to well) yah! pay up. And they do it with an RFID tag and a gate that lets them drive away from the parking garage. So there are the specifications. Okay. I notice it is very quantitative. There is nothing qualitative about this. It says here, "The RFID tag MUST" (that is a good specification term) "MUST be able to activate the gate when held 4cm or less from the gate reader." No ambiguity there. You know exactly what it has got to do. And then, "The RFID tag MUST be read within 0.5 seconds when held 4cm or less from the gate reader." Okay, That is just two of probably pages and pages and pages and pages of specifications that you would get for a product like this. Okay, so very numeric. And now you have got to design it and your study to design this thing obviously there's going to be quantitative.

Slide 13: Product Rollout! and the boss asks “Does your RFID design work??”

Okay, now let's say you go out there and you design the thing, you do all the science, and now it is time for the product rollout. Let's say your boss comes up to you and says, "Okay, the product is rolling out - Does it work?" All right. Now, this is kind of a graphic thing - but what kind of answer are you going to give to your boss. Well, it depends on how good you did your study - how well you did your quantitative methods- You could say, "Oh, wow! Dude - Who knows.". Now if you say to your boss "It's pretty good" I don't think your boss is really going to like that. If you say, "Well, Gee! It works most of the time" Most of the time isn't very quantitative. Ooo! How to give a qualitative answer to a highly qualitative product question. That is not going to wash either. Finally, "Well boss, if you hold the tag steady and close enough, you should be okay" - Well, that is a little better, but "steady and close enough"

that doesn't sound very quantitative either. Then finally, "Boss, if you hold the tag between zero and four centimeter of the reader's antenna, the gate will open within a half a second 99% of the time - that is tried." Wow! That is data. Now the boss knows exactly based on that how well your product works. That is a big deal.

Slide 14: What answer did the engineer who designed this give?

So, you had one chance to get it right. There is the car so you can (if this works) you can sort of get to see what's going to happen if you answered any of the first three ways. So here's the customer. It is within 4cm, but it's like not opening. I don't know - How do you get out of this garage? [LAUGHTER] Well that one way. Okay, so that is what I mean, you are happy with the data. You have got to prove your point. Otherwise, that guy - well - he is looking for a new job.

Slide 15: Let the Data Speak!

Okay, now what you are going to hear - is we are going to get into this whole thing about how to do this right and how to design the studies right. And what I want to start really impressing into your mind is - the nice saying about quantitative stuff - and I did this for so many years - I know this is true - is that if you have the numbers and you have collected them right, and you have done the methodology correctly- you have something that is incredibly powerful. You have data that can speak for you. In other words, let the data speak. All the engineer that I worked with - when I was when I worked in a large research and development labs - we look at a lot of different kinds of products and a lot of different technologies - they were not just the same thing every day - always the mantra was let the data speak - because there you have got something that is really powerful - something you can stand on - something you can rely on. So, the whole point of a quantitative study is to show the value of something. And if you have got the numbers you can explain how well something works or meets the specifications with minimal ambiguity - it is like that for four replies from the RFID engineer: "Boss, if you hold it within four centimeters, it will open within half a second 99% of the time you try it." Wow! That tells you instantly how well it works - there is no ambiguity. It will predict how something can or will work. That is another thing the data will do. It allows people to predict - "Ah! If you do this", then you can start making conclusions about something else. It will allow people to verify your work by redoing it. That is the nice thing about numbers - if somebody says, "Gee! You just this experiment about batteries" "you just did this experiment about processor and MIPS" "Can I trusted it?" Well, if it's quantitative, they can go back and do exactly the same thing you did, and they better get the same answers or something pretty close to it. If it isn't, there's something wrong. It is the verification and the ability to do that - the ability to repeat a study - that makes quantitative methods so powerful. And then, you can resolve selection criteria. What is that mean? What that means is look at different ways of solving the problem, different ways of designing something, you want to design the next smartphone, you wanted that RFID reader for the parking lot. Well, how do you select the components you want? Because everything is based on numeric specifications, numeric results. How close can this tag be or

not be for the reader to work? Well, I'm going to use that as a selection criteria. I want a reader that is going to read by tag out to at least 4cm. Aah! So this makes it easier for you to select components. Easier for you to select technology. Easier for you to select what kind of methods you want to use.

Slide 16: More Reasons to Let the Data Speak

Other reasons to let the data speak, you can estimate the value of a new idea quickly and clearly. So if you have a new idea for technology, you can think about how it relates to other technologies that you have available data for. And then, you can say, "Yeah! I can get an idea of how well this is going to work based on hard data." Another one, you establish your credibility. And now we start to get into things that are really important for you in your career. If you really have numbers and they're really high-quality, and they are really verifiable, nobody can argue with you. You establish your credibility and no one is going to come to you and say "How do I know you have done the right thing", "How do I know that you know what you are talking about", "Show me your degree, show me your diploma"- You say, "here's the setting, I'll show you that and here the data." And I'm going to let the data speak, that is all that needs to be done. The other thing is to teach- Okay, now what does that mean. What it means is that if you have the results of a quantitative study and this is also true for a qualitative study, by the way, Remember that a lot of these points are still crossover. And this between quantitative and qualitative - this one to teach - to pass on the knowledge of facts to others, that is this transferability. That is sort of a requirement; if you are going to be an ethically responsible professional, for just about any field, you have an obligation to teach. In other words, you just had a discovery; you just got a patent, you just came up with a way of doing things that nobody else has thought of, you just come up with a new algorithm, etc. You have to teach; you have to tell other people of your discovery and let them benefit. If you have a hard number - hard data, then that becomes very, very clear easy. Here is the algorithm; here is a way to measure it; this is what you do. And you can communicate in a way that others can understand. Units are units; Volts are Volts. Things like that. Other engineers can immediately understand what you are talking about. So, many Joules are available from an energy source on this battery. Aaah! Somebody trained in the field can understand that. And then, it also removes useless elements from the technical discussion. Viggo is a good one. The boss thinks he knows more than you. Well, fine, ask the boss for the data. Show me the data, boss. Somebody comes in and says, "Hey, I've got a degree from KTH; yours only came from yeah. Okay, show me the data." All of these unnecessary things are removed. You can now base analysis, discovery, and opportunity on hard data - that is objective. Okay, now there are two approaches to experiment design, and you are going to run into these. And this will be discussed in other lectures (I think).

Slide 17: Two approaches to experiment design: Deduction and Induction: Deduction

You probably have already seen some of it, but this is a good {analogous} sort of summary of how to think of your studies as well. There are two ways: deduction and induction. And

you can use both quantitative and qualitative methods for both. This is useful now you are starting to characterize what you are doing in this class. This is also very useful for when you get out into the real world. And you start thinking about what kind of professional studies am I doing: Is it in inductive or deductive. Think about that RFID parking example. Okay, so a deductive study - deduction - in this study, and you start with a hypothesis. What's that? Well, hopefully, a lot of time will be spent in this class in finding what a hypothesis is. It is just a fancy term for say, "I think something is true" or "I think something will work out a certain way". You already know what it is that you are thinking, and it has to be something that you would have to do a study to really be able to understand - if it is true or not. In can't be something that is obvious. So, you start with a hypothesis based on a known fact, a physical law, or some kind of theory. So based, for example, on chemistry and physics, you could say, "Aaah! This new way of designing a battery, my hypothesis is that it will last at least two times as long in the same electronic platform as the existing batteries." Aagh! So, you already have a theory that you want to prove. And then what you do is you seek to confirm or reject that - based on your study. So, you are going to go out, you are going to collect the data, you are going to analyze the data, and then you are going to say, "Yes! It lasts at least twice as long." or "No, it doesn't". You are going to confirm or reject it based on the study. So that is called a deductive study. So, this is the general path: you have a theory this chemistry on this - this chemistry and the physics of this particular compound look like it can store a lot of a lot of energy. You come up with a hypothesis: "Hey! I think I can store some much energy that it is going to last twice as long as my existing solution". You do the observations and the measurements, and then you accept or reject. That is a deductive study. So ask yourself when you are looking at your study: Is it deductive, or is it inductive?

Slide 18: Two approaches to experiment design: Deduction and Induction: Induction

Okay, for induction, this is a little bit different. This is mostly characterized by a study where you don't know yet what the hypothesis should be. So, in other words, you really don't know. You start asking questions. What do people think about the air quality in Stockholm? We don't really know one way or another. You don't know if they think it is good. You don't know if they think that they are about to drop dead breathing it. You really don't know. You want to come up with a hypothesis - but you have no clue at this point. Aaaah! So, you don't have any existing theory, laws, or facts. You just wonder: "What do people think is the air quality?" So, instead, what you are going to do is you are going to go and perform a bunch of experiments, and you are going to observe those results. One way is to go out and interview people. "Hey! What do you think of the air quality?" So, we start what could be a very qualitative or quantitative study, and then from those results, you see (hopefully) a repeatable pattern - something other than just random data. You have something that you say, "Hmmm?" Yes, this is where data science comes in. This part of town, in this part of Stockholm, on this island, we see people sort of agreeing with each other - over here and maybe not so much. So, in other words, you start seeing patterns of some kind of repeatable outcomes and then based on those patterns of repeatable outcomes, you come up with a

tentative hypothesis: On Kungsholmen, people think the air quality is good. Aaah! Okay. Maybe and that might be your hypothesis that that you have now formed, and you are going go on and design a study now to verify it or reject it. So, it could be the basis of a new theory. So, I call this a "What if ... " study. We do these a lot. Well, there is the general outcome there at the bottom. Start with some observations - you are going to look at the outcomes. And then, based on that, you are going to look for the trends - things that sort of correlate together and form that you are going to generate a tentative hypothesis. And then, you are going to go on to try to prove it and generate a theory for that. That is an inductive study. So you have kind to want to think: "okay, where does what I'm trying to do fit in." Another way of looking at it is - don't think that every study you do has to start with a hypothesis. In an inductive study it won't - it will end with a hypothesis. So be aware of that.

[Student asks:]Where is the dividing line between the theory and the hypothesis? For example, I was [UNINTELLIGIBLE] a hypothesis is like a statement. And except for [UNINTELLIGIBLE], while a theory describes the way of your working or how does something work -[Professor Smith] Sure. So a hypothesis is something that you can prove or disprove. Exactly. And you have to already have a basis to be able to do that either by designing the right study and getting the right numbers or some other way of determining whether or not it's true or false. The theory then gives rise to a way of saying, "all right here's the theory that drives my next study". So, in other words, the theory in a deductive study already exists, like, for example, the chemistry and physics of the battery, but for an inductive study, the hypothesis gives way to the theory that you are now going to use design your next study. Which hopefully will be deductive so you can accept or reject it.

[Student asks] Well for Kungsholmen, people are already happy with the air quality. Would the theory be that there are more trees over there or like ....

[Professor Smith] Exactly - that is it - yeah, that is what you are doing is you are using your tentative hypothesis to create or derive a theory. Yeah - that is it - exactly - maybe there are more trees - more greenspace - maybe the wind patterns are different - maybe there are fewer buses - but yeah, you are going look at your data and come up with that driving theory. Exactly, you got it.

Slide 19: Deduction and Induction Which is better?

Okay, which is better? My point is that neither is better. We will finish with this slide and take our break. This is a very good stopping point. But use these as a guideline. It all depends on the problem you are trying to solve, and this now gives rise to the problem - the whole point of the problem statement. We will talk about that right after the break. But if it's based on known theory - exactly what you were asking yeah - you start with that you have got your hypothesis - you know you have got a deductive study. If there is no theory yet to base it on, then it is probably going to be an inductive study. And then, realize that neither approach is perfect. Okay? Something can be proved - the hypothesis can be proved only within the rules which you established - you go outside of that sphere, and you are outside of those rules and all of a sudden the study will fall apart - so there is no room to deviate in a deductive study - you have to stay within the rules otherwise your results not good. But the

inductive approach does give you more room to deviate from the rules because we don't have the theory yet. So that is one of the nice things about an inductive study; you can generate the rules which you will then following in your next deductive study to accept or reject your hypothesis. So, everything stays tentatively until the theory is proven. So, use these to help you decide what kind of study you are going to do and how to [do it] and then, of course, design the experiment to perform in a high-quality way. We are going to take a break come back a quarter after, and what we'll do is move on to the real aspects of quantitative design which you need to have.

Slide 20: Ingredients of a quantitative study

These are Mark's ingredients - in most cases, most people cooking up a quantitative study would agree with these ingredients. I've put a very much industrial twist on it because I know that these are the sort of ingredients that did me very well when I was in industry. I know this is what manager in industry - When you go out working in industry what is your boss - what is she going to ask for. Well, she's probably going to ask about these sorts of things. So, these are very, very industrially focused, they're going to be very useful whether or not you have an academic career or an industrial career. So, here we go - it doesn't matter if your state inductive or deductive - I'm talking about quantitative here, and these are the general steps so that you have a good reputable study. And I can pretty much guarantee if you do this in this class, you will probably get a pretty decent grade. Okay? Things will go well. Well worth it. Okay? Problem Statement, Literature Study, Experiment design, etc. all the way down to references. Each one of these things has a point that you have to take into account - when you are doing a quantitative study. But one thing I want to illustrate about this slide first is that these things are not disjoint pieces. So, in other words, your problem statement is not this completely disjoint thing that has absolutely nothing to do your with your literature study or your references. No, all of these things have to be coherent. All of these things have to have something to do with each other. If you go through and do these steps - we are going to go into a bit of depth on these steps in the rest of the time we have today. But as you go through and you do process control for any study which is quantitative - ask yourself what's the connection between these pieces - if your answer is I don't know - Stop! Because there has to be a very, very, very clear connection between the pieces. If it isn't there, then your study is going to fall apart. So, they're very, very dependent on each other. So, let us go through these things one at a time. Since all of these things - you can find in some form of the templates that you use in this class. It is just that I may have separated them on a slightly differently worded way to drive home why they are important.

Slide 21: 1. Problem Statement

So the first that I'm going to do is the problem statement. This thing is without question the most important part when you are beginning your study. You have to articulate it. So what is it? What this is - is what is the problem or question you are trying to solve. An I noticed in section E when people were just starting and of course, you had not heard of any of this when you started. People were coming up with ideas for the projects without first asking this - you

have got to have this. And you need to make this very, very, very clear at the start of the study - what the heck is it you are trying to solve - tell me what is the problem? What is the question? I need to know that - because what it will do is to define the scope and purpose of the study. You notice for a lot of you - you would come up with a problem statement, and then all of a sudden we say, "well, you are never going to get that done in seven weeks". You might not get it done in seven years! Right? So, it helps to establish the scope of the study and, of course, the purpose of the study. Why are you doing it? What is it for? There can be a whole lot of different reasons - the actual reason doesn't matter; there has to be appropriate stuff. It also serves to give specifications that define your goals. In a quantitative study that is also paramount - what are the specs. You say you are going to solve the problem - well give me the specifications that let me know that you have solved it. So, that is another reason - if you don't know what the problem is, then you don't know what the solution ought to be. Without that problem statement, there is no way to form a hypothesis. Right? A hypothesis is something you are going to prove or disprove, and if you don't even know what the problem is, you are trying to solve, then how do you know what to prove to this group. So, you can't even do a hypothesis if you don't have a problem statement. And without it, like I say, it is very hard to judge the results - nobody's going to know what you are talking about. So, in other words, if you give somebody a bunch of data but you can't what it was trying to solve - well - the data doesn't mean much. Right? So, in other words, without a problem statement, your study has no bounds - you have no idea where you are going - and you never know when you get there. So, first and foremost, what is the problem that you are solving, and that is really important - you want to your thesis your master's thesis - Wow! The quickest way to get your examiner jumping up and down with steam coming out of their ears is not having a problem statement very, very well defined. And also don't do that to your boss - or Your boss will come back and say, "I thought you knew what we did in our company. I thought you knew the kind of products we are trying to make." So, make sure the problem statement is there.

Slide 22: 2. Literature Study

And next is the literature study- The whole thing all about the literature study is really to show that you know something about the problem you are trying to solve. Okay? So, this is really an important step. Now, often what I see in science reports - and I've even seen this professionally - you would be amazed how many scientific papers I am asked to review - that a problem statement will be given, and they will be missing the literature study altogether, or the literature study will just be so incomplete that you get the impression that the researchers have no clue what it is - on the field they are doing research in. So, in other words, this goes with that saying, "knowledge is power". What do you know about the field of the problem space you are trying to solve - if you know absolutely nothing about the problem space you are trying to solve - then how do I know that you are not just solving something that somebody's already done. How do I know you know just coming up with re.-inventing the wheel. I know if you have anything of enough knowledge to be able to solve the problem at all. You do that by demonstrating that you have that knowledge and you get it from any published knowledge base - like journals and conferences. So, in other words, in order to be

credible in solving whatever it is you said in your problem statement - you need to know what has already been done and what were the outcomes. In order words, you have got to have some expertise there. You won't repeat the mistakes that others have made. Okay? Clearly, your boss is going to want you to do that. You know the challenges, the successes and failures that others have identified with experience. This is actually _very powerful_ because by going back in the literature, you are going to see other opportunities. Oh! They couldn't solve that problem. Well, I think I've got a solution. Oh! They did this. I think I have a better way. The literature will really help you to focus in on the best problem to solve. So definitely do that, and then also you know what your expected contributions are. If somebody says, "Gee! That is a great problem, but so what! Why do I care?" You can say, "Well, look at all these other researchers out there they've been doing this and this and the couldn't do this, and they sort of do this, and this wasn't very good - and if you do all these things - and Oh, by the way, based on the literature this is an xxxx billion euro business and if we do it, then ..." You get the point. You are biasing it again on hard data that you are reading out of all these other sources that you have access to. And, in fact, that a lot of cases you might be able to solve your problem just from data presented in the literature. You don't need to do an experiment. This is something that a lot of guys in this class, a lot of a lot of previous students haven't realized they want to go to find some data and they want to do a survey to try to answer some questions. Then people go running around trying to do a survey, but it may very well be that the raw data is already there. This is what data science is this all about. This is what big data is all about. That is why those repositories of data about what everybody's doing is out there. You don't have to go and collect it. Guys like Google and others are doing it for you. Just use it! So, the point of the literature study is to convinced me you know what you are talking about. Convince me that the problem we're solving is real. Convince me that you are not doing over again with somebody else has already done. The literature also has another point, when you get your results and your conclusion, you can tie it back to literature studies say, "based on my results, I've done better than these other researchers have done." So, in other words, that tie has to back - you can see the connection between the problem statement and the literature study. And eventually, your conclusions have to look back to the literature study and be able to say, "we did better than ... or we show results that were ..., with respectively to these other researchers." So, the literature study is really important - without it you have not credibility, and nothing stands.

Slide 23: 3: Experiment Design

The next is the experiment design. In a quantitative study, the whole thing is that you have to completely describe how you designed your experiment. It can be really really simple you are going to use a voltmeter to measure some voltage. Or it can be something really really complicated - you are going to going to an integrated circuit fab, and you are going to be looking at new ways of processing masks or something. I don't know. Or new ways of actually making integrated circuits. So, it can be very complicated or very simple, but it doesn't matter. The point is you have to make your studies repeatable. That is another one of the reasons why quantitative studies can be very powerful. If you transfer your results and transfer your methods, another person can do your experiment and verify it. And if you want

to be taken seriously, you want to make sure somebody can do that. If nobody can reproduce your results, then nobody can be expected to believe them. So, that is why you have to be very clear you need a full description of all materials and methods that you used. Everything! A full description of all equipment and processes. I don't want to know that you used a voltmeter, I want to know what voltmeter, Who made it? What model number was it? Why? Because it's got everything to do with, well: What's its accuracy? What's its precision? How good is that voltmeter? It may be that you are not measuring something under test, you might be measuring the performance of a bad voltmeter. So, Yeah! I need to know what that is. I need to know how you used it. What was the way that you used it? All materials, sources, and suppliers - Where did you get your chemicals? Who provided them? Where did you get your materials? Where did that copper sheet that you used or the dielectric come from for the circuit board which you used? I need to know all of that if I'm really going to reproduce your study. Full description of any human or animal subjects used. You need that just for ethics. But who are they? I really want to know, not just if you are going to do {like} medical experiments - it goes beyond that. Where were the populations of people you surveyed? Were they in Stockholm? Were they in Norway? Where they in North America? South America? Australia? I don't know? Where the male or the female? Where they kids? Were they teenagers? Were they're old folks, etc. If I don't know that - I can't reproduce the study. I need to know all those things. Full description of the environment under which the experiments were run and data collected. You did it in a forest? Tell me about that forest. Was it summer? Was it winter? Was it raining? But If you a laboratory - okay - but was there anything special about that laboratory? Let me know. Where was that laboratory? So, in other words, I've got to have independent verification of your results. By independent, I mean that anybody else out there should be able to reproduce your results. Also, one other thing, and if there is time in this course - we can have a lecture about it. If you think you are going to get intellectual property, like patents, one of the rules for getting a patent - patents are good especially if you want to start a company or something - that can be very useful - base your first product on a patent for something that gives you exclusive rights - to be able to design and build something itself - but one of the rules for getting a patent is that whatever it is that you are patenting must be able to be reproduced by someone "skilled in the art" - that is direct legalese wording from the idea of patent. Well, if somebody who's just as good an engineering or computer sciences as you are can't reproduce your results - you ain't going to get a patent. So you have to do all this if you expect anything that you discovered to be patentable. We can talk about that later it is kind of fun. Okay! We are now on to the fourth step. A point about the third step - make sure you completely describe your methods and, of course, convinced me that this will help solve the problem - obviously it has to be a method that leads to solving your problem.

Slide 24: 4: Data Collection

Another thing and that is the data collection. You want to describe the nature of the raw data that is collected. For a quantitative study that is easy - Volts, power, something like that. Maybe some sort of some sort of chemical phenomena - we don't know. But it is something that is described by numbers and has units -so that is easy. So, it needs to be measurable

quantities, and it takes into account the following three things: accuracy, precision, and resolution. This is absolutely paramount when you are doing a measurement. We will talk about what that means future lecture - if you take my sensor systems course next term - you will really get into it because that is very quantitative in nature. But I need to know these things because without knowing them, I don't know how good your data is. And, in fact, ignore those things, and your data that you collect may be worthless. So, yeah, you have got to be careful of that, You have to look at avoiding any biases that the data might have. So this is part of your data collection strategy. What is a bias? This is anything that comes in and essentially influences your data. This sort of a thing. So, in qualitative studies there's lots of different ways you can bias your results. Surveys are notorious for having leading questions that could bias the result. You have to be careful in quantitative studies about biasing your data - biasing your results. For example, maybe the environment is producing some kind of signal or some kind of phenomena that you actually end up measuring instead. I can tell you zillions of stories about real laboratory experiments where we have seen incredibly unimaginable bias. But I won't take up your time now that. But you have to be careful about where any kind of things that can sway your data or cause it to be different from what you really want measure can come from. And the amount of data that is collected is important. How many measurements do you need? Well, if you only take one measurement, you can't tell me any about the precision of your measurements at all. So, okay -you failed there. Well, do I take five hundred zillion measurements? You know - maybe. What other measurement strategies are there? So we are going to start talking about those we start to talk a little bit about quantitative methods of measuring for statistics. But the bottom line is that you have to take data that is consistent with the way you are going to analyze it. You have to know what is going to be the process by which you are going to analyze your data. And then know enough about how that analysis works - so that you can get enough data of the right kind. So, that is what is important about your data collection. And you can see that it is tied to everything else. If your data doesn't match or server to solve - to answer your problem and if your data is nothing that relates to anything you have read in the literature - well then - okay- something's broken. You are not getting where you need to go.

Slide 25: 5: Data Analysis

And then there is the data analysis itself. So, you are going to end up with a bunch of raw numbers. Great! Okay! Lots of voltage numbers, lots of speed numbers, or something that you that you get from (I don't know) some kind of analysis software tool. Great! Having pages and pages and pages of sometimes gigabytes of numbers doesn't really help. Think about big data there's like like so many terabytes of data sitting out on cloud servers right now - What does it all mean? Obviously, nobody's to be able to root through all that data and get any sort of meaning by just looking at the numbers with their eye. So, you have got to have some way that you could summarize your data. And you want to do it in a way that any competent researchers can understand what your data means without having to look at every value. So, quantitative data is relatively easy as long as you know the method that you want to use to analyze it. But it also allows your data to show trends, variance, probabilities, errors, and other quantities. That is what's cool. So, if you do a study and all of a sudden, your data

shows a trend. Aaaah! You might be on to something really new. You might be on to some really new technology or really new methods. This is now called data science. It is what a lot of people use - call data science -they go out, and they look at huge pools of data and then try to identify trends, variance, probability, errors, correlations, and other thinsg that let the data speak. That is what you need to do is come up with ways to be able to do that. And then you will want to be able to show the significance of the data. So, in other words, pages and pages of raw data doesn't say much - but if you come up with a good analysis - that should say what the data is good for. In other words, what is the significance of the data? What does the data really mean? There it is - at this point, the data is really starting to speak. It means this. It may mean that your experiment didn't show what you were hoping to see. In which case, you can reject your hypothesis - but that is significant. Don't think that negative results are insignificant. There are not. Properly analyzed data is always significant.

Slide 26: 6: Study Conclusions

And then, the study conclusions. This is where your boss is going to run. So your boss - well so even if your boss came up through engineering, science, some sort of STEM field - your boss has a different job than you. The boss or society or whatever it is if you are doing the study for the benefit of - probably is not exactly the same as you - and what you need to have a different job. So, what you need to do is take the significance of your data that you did in the previous step and interpret it. That is really what's going on with your study conclusion. It is here where you connect the data with the hypothesis. So, in other words, you are going to look at the outcome - the significance of the data, and based on that you are going to accept or reject your hypothesis. "This battery lasts at least two times longer than the existing solution battery in this particular device." Okay, after taking pages and pages of data and analyzing it - look at the significance of that and say, "yep it did - I accept my hypothesis - it lasted two point five times longer". Or say, "Well, it didn't quite make it. It only lasted one and a half times longer - Reject!". But you are saying what it means. In an inductive study, you can come up with a tentative theory. "Hmmm, People on Kungsholmen seem to think that the air quality is better". Aaaah! So, I have a theory now - Can I come up with a hypothesis that might be the basis of another study. Okay, you can say what the impact of your study means. In other words, what is this is really mean: Well, I have a new battery technology that is now going to revolutionize IT products. Wow! That is what your boss wants to hear. That is a conclusion. That is, that has been distilled out of all the numbers. Or I went out to solve this problem or answer this question - here's the solution. Here is the answer. That is what this thing is doing. So you have gone from data to the analysis, and now the confusion finally answers the question that you were trying to solve. So you can see that this has to tie back - this has to go back to everything. Without this, you haven't answered your question. Also, you can see that this has to relate to your literature study. You have to show: How does this compare to what others have found?

[Student asks] If you state a hypothesis - are we going to rely on a quantitative or quality study?

[Professor Smith] It doesn't matter - you can have a hypothesis for either kind of study. It just depends on whether it is deductive or inductive.

[Student asks] Can you [UNINTELLIGIBLE]?

[Professor Smith] No, I - I that is difficult to do it in a quantitative study; it deals with numbers. If you are bringing in something that is not objective and it has units attached -- like good or bad - it doesn't - you have to be able to map it to numbers with units. So, there it is. So, now you can say what about your problem statement has been solved. Okay, things like that. These are typical outcomes of conclusions - "The technology is possible and will be disruptive in the market." Oh! Your boss is going to love that. Okay! Definitely! Move on with it. Keep going. Bring it on to the market. "The basis for an entire new industry can be created." In other words, these are what your data really mean. This is the distillation of it. This is more expertise having collected this data. This is the "So What?" You can see how everything has to tie together. If anything is disjoint and definitely in the report, we want to see it tied back to the literature study: "We were this much better than these researchers" "We solved these problems that these researchers couldn't do" Etc. Etc. Etc.

Slide 27: 7: References

Okay, and then the references. Now, this is another one that I think a lot of people get really bored with. And they think this an unnecessary hoop to jump through. Okay. References really are important. Now, I will tell you this - nobody's going to be a raise based on the number of references in your technical reports. And your grade is _not_ proportional to how many references you have in your reference list. It has nothing to do with that at all. What the references are is they tie back to your literature study and the rest of your whole report - the foundations of the information that you have found. So, in other words, they back up their claims. You claimed that this is a problem. Oh ya? Says Who? Well, these guys say it is a problem. These researchers have been trying to solve it for years. You have to have the references in order to do your literature search. So this backs up the claims you made. You might make some sweeping generalization: "Smoking is bad for you". Oh Ya? Who says? You said it? Well, that is not good enough. Oh! Well, all of the studies have said. Aaaah! Okay. So don't make a claim in your report without backing it up. "Busses in Stockholm are an average of thirty minutes late." Oh yeah? Who says? You better have something that backs up your claim. So, if you have any claims in your report - now that doesn't mean don't make claims. Yes, you have to make claims, you are trying to say something. You are trying to prove something. You are trying to solve something. But when you make a claim, back it up. It also provides a base of the previous work. But the most important thing is that it allows the reader to share resources - so they can understand where you are coming from - and it also allows your readers to verify your sources of information. This is really important because it establishes a lot of your credibility. You make a claim. Who says? Oh! Wikipedia says. Forget it, done. Wikipedia is not a reliable source of information. OH! You got your information from them. No good. Show me that it is a reputable source of information. Aaah! Oh! I got it from these IEEE journals or transactions on whatever the

heck it is. Well, that is different. That is peer-reviewed. That is moderated by editors. The quality of those sorts of publications is, in some way, verified.

[Student asks] But Wikipedia does get some of its data from IEEE papers So we could just look for what kinds of papers ... these numbers come from ...

[Professor Smith] Well then cite those papers. Yeah!

[Student] I wouldn't argue that Wikipedia is fine so ...

[Professor Smith] It doesn't work. Wikipedia is not peer-reviewed. So sorry. Yeah, It's just not going to make it. So I - I strongly suggest that you do not cite Wikipedia. Use it as a basis to find other papers - for sure - do that and then make sure that those papers are reputable and realize that nothing is peer-reviewed in Wikipedia. So, I can cite everything I wanted, and then I add a few more things that make no sense at all - and no one may catch it. So, I strongly recommend you don't do that. And it [your references] also provides the background needed to replicate the results. If somebody really wants to replicate your study - well, they sort of sometimes need to go back to leverage from the same previous results that you leveraged from. If they can't find it, then that doesn't help. They have got to be able to have the same background as you had. The same previous studies and information or data sources that you had. If they can't find it, then they are not going to be able to replicate the results. So, this is really really really important - you only need as many references as you need to solve your problem. Don't add a whole bunch of references that are not cited anywhere in the text- that is just fluff - that doesn't help anybody. Get the reference you need but only the references you need - you don't have to search for a hundred years. Make sure you do a thorough search. Don't cite the first thing you see - look for other things as well - because different - especially in a qualitative study. Okay. Now to wrap up. We talked about quality and I think I made a pretty brazen claim - didn't I. Wikipedia is not reliable, I said. Now don't get me wrong - do I read Wikipedia - you bet - a lot- it's a great place to start - it's a great place to say, "What is it that I'm trying to find out?". Read a few things and then move on. Go to their references and just keep going, Yes, of course, I use Wikipedia, but no, I don't cite it. But how do I guarantee what high-quality is? What is quality? Because ultimately, forget about this class for a minute, long after you have forgotten about II22020, What is going to be the basis on which you have to generate these reports and presentations- like the embedded systems guys were talking about - and have really high-quality. Well, you can use these this list (a relatively short list) on the next three slides to really understand what overall in a study what quality is.

Slide 28: Quality in Research: Validity

so the first thing is validity. Okay, How trustworthy is your study. You say you are going to measure something. Well, okay, did you actually measure what you said you are going to measure? Air quality - are really measuring that, or are you just measuring somebody's opinion about it? And this sort of a thing. Battery life - are you really measuring that? Or are you measuring something that isn't that? For example, power very, very often, I've lost track of how many students' studies - where somebody comes back and says, "I'm going to show

you that the power- I've got more power in this energy source. Look, it provides a hundred milliamps!" Okay, Obviously that blew the study out of the water -because milliamps are not [units of] power. That is not a measurement of power. So, make sure that you are measuring what you think you are actually measuring. And that the study is credible. That you have followed accepted rules and procedures. That is what this course is all about - the methodology. Did you really follow accepted scientific method? If you did great. If you didn't, nope - again, you lost your validity. And that you have valid outcomes. That the results are correctly understood. So, you have data - you look at the significance, and then you can make conclusions. Right? Okay! Can somebody who looks your data and looks your analysis of it, can they come to a similar understanding? Or does it mean to them something completely different? Now that isn't bad in a qualitative study, but in a quantitative study, you start to question it. If 2 means 2, why is somebody coming to a different conclusion? So, you need to really understand did they understand your results. Have you expressed them in a way that people understand? That is high-quality.

Slide 29: Quality in Research: Dependability

Another one is dependability. So, in other words, it's the stability of our measurements and the consistency of the results. Now, this is - this is a hard data sense for a quantitative study. This gets back to accuracy, precision, and resolution. I was always amazed when I worked in an electrical engineering and computer engineering laboratory, how few of my associates knew the difference between accuracy, precision, and resolution. Learn what that is and burning it into your heads. We are going to talk about it. But that is about the stability of your measurements. If your measurements are not stable, if they are all over creation, if you have got terrible precision - well, you had better be able to analyze it and bring that out. And have your study show, "yeah, the answer is this, but it's not very precise." That is dependability. Also, do you have processes to audit every phase in the study? You are going to do that in this class by peer-reviewing each other's papers - as you go along. That is the point. You are trying to guarantee high-quality. You are trying to say, "yeah", but you didn't do this, you didn't do that, what about this process? So, know what has to be done and know how to control what process does. And then, of course, peer review the results and have a full and available report on every phase. Well, that is your - that is the project you are working on, that is the paper that you are generating. It is a report of what you did for each of those phases. And then, of course, peer review the results. Thus, the Wikipedia problem. If it isn't verifiable by others skill in the art and others are very, very knowledgeable in the field, then the dependability of your study is a little shaky - because other people can't back it up - this is good sound work.

Slide 30: Quality in Research: Confirmability & Transferability

So, that is important, and then finally, there are these other two terms: confirmability (if that is a word) - what that really means is have you I acted in good faith. Meaning? Okay. What went into the data? Now, this is dangerous for qualitative studies. This is a form of bias. In other words, have you biased your results? Let's say that I live in Norrmalm, and I'm

convinced it has the most sparkling pure air in the world. And I'm going to prove it because I live there and I really like that neighborhood. So, of course, those guys on Kungsholmen don't know what they are talking about. Okay. Don't do that. Don't let personal opinion come in and bias your result. You are the researcher; you have to stand back up and be absolutely separated from the data that goes in. Unless you are analyzing yourself at some point. But, you cannot manipulate or affect the results of the study. So, probably a lot of you have looked in the newspaper lately or actually over the last several years - occasionally you see an article, Herr Doctor Professor so and so - big shot at highly ranked university has to retract results because Oh! Well! Ummm! there were some irregularities that went into those results. Well, if you are Herr Doctor Professor at any place, that is probably the end of your career -so don't do that. Do not manipulate or affect the results of your study in any artificial way. That is bad. It is definitely bad if you are in finance - where it is called "cooking the books". The other thing then is transferability. Does your study have any useful output? Now. You could argue that useful output is just expanding the range of knowledge. And I would argue that that is true. I think it is great - anything that helps people to understand more about who they are and the world they live in, anything that contributes to a body of knowledge - is an example of transferability. So, descriptions, data, methods, processes, any output then becomes a database of use for others - even if only in thought - is good enough. So, this is a very broad thing. It is hard to decide it is completely useless. But still, you should be able to convince yourself and others that there is something about it that is transferable and useful. And that will help guarantee the quality. So that is really it.

Slide 31: Next steps for you to take

So, the next steps for you to take. So, a lot of them were still thinking about your topics, a lot of you are still thinking about what you are trying to do in this course - but it ain't going to be the last time - most of you are now going to be faced with what you want to do in your jobs, your careers, product going to design, the companies you are going to form. So, this is a good place to start - ask questions and work it out. So takeaways. I have mostly talked about quantitative, well - that is because that is what this lecture was about. But there is no better thing. Okay? I'm not saying that quantitative is better than qualitative. It's just all about the problem you want to solve. That is really it. So, there are lots of methods and techniques and processes that can help you do good quantitative studies and get concrete results. Look at them all; there is no one particular way. Just like there is no one particular kind of study that is good. If you are going to do a quantitative study, there isn't one particular method – there are a lot of ways that will lead to results. So, be broad and this is one of the best reasons to do a literature study - because some of the guys out there will have done some amazing work using very interesting methods. Why not see what they have done? Why not use a method related to them? The other thing is, of course, always let the data speak. That is what the whole quantitative thing is about. If somebody comes up and says, "What is the result of your study?". Just say, "here are the numbers." Always let the numbers speak. Don't fall back into a qualitative thing. "Oh! I thought it was good." "Oh! I think we're going to do this way." No! Know why you are going to do it that way and what is the kind of data that is going to come out of it. That you wanted the data to speak to you. You are not going to get

and say, "I'm right!." You are going to say, "I'm right because here are the numbers." Let the numbers argue for you. Okay. So, in the future were are going to go into the details of a lot of these and focus on what's important, like accuracy, precision, and resolution. How those numbers can be properly expressed. What kind of statistical analysis you might want to use to show things, and how do you want to collect these numbers.

We already know that collecting one data point is probably no good, but how many do you need. Okay. We are going to talk about this. But also in the lab sections were going to try many of these methods, techniques, and processes. Now one thing is definite - when you let the data speak - right? The data is speaking and not you. So, that means if you are reviewing somebody's work - yeah - concentrate on the data, concentrate on the processes, concentrate on everything that is up here. And definitely learn to think critically about it. You are not attacking the author - you are not attacking the person doing work - you are looking at the methods, you are looking at the processes, you are looking at all the steps and saying what is the relationship as I go through three. So, your job in the class is to start thinking about as a reviewer - start thinking about how do I really critically look at some other piece of work. What is the data trying to tell me? Etc. If you get good at critiquing other people's work - there is no personalities that comes into it - it is only the work you are critiquing. You will get good at your own work. It will really really help you have a high-quality in your own work. Okay? So, any questions? Any comments?

[Student asks] Are there any techniques when it comes to quantitative data analysis - what I see is that this type of analysis relies on statistical methods that are [UNINTELLIGIBLE] data site. So are there like any known techniques when it comes to quantitative datasets that this is one way or another.

[Profssor Smith] Yeah Yeah I can recommend a lot of books. So there's something very very- especially now in the day and age of data science - where people are going out to huge data sets, and they want to do this kind of numerical analysis on quantitative data to be able to come up and look for trends and other sorts of things. So there are a lot of different methods for doing that. So there are some good references I can give you. Most of them are based on classic statistical methods, but there are a ton of different tools. In fact, if you just look at something that most of you may already have Excel. Excel has a huge number of statistical tools that are hidden in there - that you can use to do all kinds of data analysis. So, yeah, the answer to your question is yes - big time.

[Student asks] For your next lecture, could you also cover like you know which types of graphs we are supposed to use in what kind of scenarios. You see, you have these different types of graphics like boxes or ___ Many other types and R and SPSS have all different things. It would be quite good for us to know which kinds to use.

[Professor Smith] I am reasonably sure there will be some sections about visualization. Yeah. You are absolutely right - visualization is really important. How do you want to present? That has got everything to do with effective presenting. So, a really good point, and yes, we will do that because effective visualization is the way that you convey understanding. So you have to have it. So, yes, we will.

[Student asks] Will there be a lecture about the academic world - what is a journal like [UNINTELLIGIBLE] what is a workshop, peer review, and how things work there and how you can participate, take part, etc. ?

[Professor Smith] Okay! So, okay, here's a deal if you are a Section E, and you want to know that stuff I'll tell you. If there is going to be a section, I'm sure there could be, or part of a lecture at least given in this course - yeah that would be really really really good to know, and in fact, that is a really important question actually because when you go out and start looking at the literature - so you know you have already said "Aaah" You might not want to Wikipedia. So what should you rely on? What is considered high-quality, and that plays into exactly what you are asking. So, yes, that is important - yes, we should cover it. Look for you know that appearing in the schedule, and certainly in the section, I can cover it in my section if you like. So yeah that is a really really really good point. If you want to get some high-quality references. Any other questions? Come on - you guys are too polite. Ask me. ... Okay. Thank you.