Problem 1:

Explain in your own words why a higher Analog to Digital Converter resolution (in bits) results in lower noise due to quantization.

Noise due to quantization is the error between the original analog signal and the quantized digital signal. More bits means more resolution. With more bits, each bit is responsible for a smaller range of analog values, leading to lower error.
Problem 2:

In class and in the notes, you saw how sensors transform variation in real-world parameters into changes in measurable electronic quantities such as potential difference, current, resistance, etc. using simple circuits (see the electret microphone). For each of the following parameters, describe a simple electronics circuit or scheme (please do not tell us you will measure pressure with a “pressure sensor”) that would allow you to measure it. Essentially, design a sensor! Remember Occam’s razor: Keep it simple!

Most of these are commercially available and fully detailed on Wikipedia. Remember this isn’t graded for correctness, so if you don’t know how each of these might work, do yourself a favor and be creative!

A. Pressure on the ocean floor.

B. Frequency of a guitar string (guitar pickup).

C. Rotational speed of a bicycle wheel.

D. Frequency of breathing at night.

E. Imperfections on a knife blade not visible to the naked eye.

A. Use two parallel capacitive plates. The distance between them should change with applied pressure.

B. Record sound with a microphone, digitize it, and take the FFT.

C. Place a break beam sensor in a fixed position on the bike that is broken by an object a fixed number of times per second.

D. Wear a shirt with a strain gauge that measures the rise and fall of your chest.

E. Use a capacitive sensor as in A. This sensor can measure the distance between the knife and a plate, thus mapping out the surface of the knife and identifying imperfections.
3) A) Police lookout vehicle/trailer.
   → For crowd control during protests.

   [Diagram of lookout tower on post rigidly attached, with label: lookout tower (on post) rigidly attached.]

   [Diagram of trailer hitch with label: trailer hitch.]

   [Diagram of wheels with label: wheels.]

   [Diagram of ladder with label: ladder.]

   [Diagram of bearing with label: bearing.]

   B1) St. Venant's Principle → wheel axles way too long, wheels way too far from bearings, which appear to be too short.

   2) Abbe error → the lookout tower, which is rigidly fixed on the post, will be significantly skewed to one side (tilted) if the trailer is not on flat ground.

   3) Centers of action, the center of action (gravity) appears to be very close to the rear wheels, with the tower post behind the rear axle! The trailer may tip back.
3) c)

1) Shorten axles, lengthen bearings.

2) Add DOF's to platform-post joint to allow leveling of platform once in place.

3) Move post forward, perhaps lower post and platform when moving trailer to lower center of gravity for turns, braking, etc.
4) A) Due to caster wheel design, friction does not constrain DOFs, so same with and without friction.

4 DOF

(5 if you count rotating the whole chair and just the seat as separate DOFs)

(+1 if your chair can raise/lower the seat)
4WB) No friction: 3 DOF

Friction: 2 DOF but they are linked

→ Forward/reverse translation.

→ Rotation on plane only when translating forward/reverse.

A) C) No friction: 5 DOF: 3 rotation, 2 translation

Friction: 3 DOF: 3 rotation.

A) D) No friction: 4 DOF: 3 rotation, 1 translation

Friction: 1 DOF: 1 rotation.

A) E) In operation, 4 DOF: 3 rotation 1 translation

but all linked

Cannot rotate without translating forward, allowing control raps to create pressure differences that rotate the plane in 3 axes.
4) B) The chair is overconstrained! Only 3 contact points (legs) needed to sit flat on a plane.

This is possible due to elastic averaging. The load on the structure (you plus lunch at McDonald's...) causes the structure to deform to a point that all 5 legs touch the plane.

Ever notice that when you sit in a chair that is "wobbly" (rock back and forth between different sets of 3 legs) it suddenly becomes stable?

→ Elastic Averaging
5) A)

You are violating kinematic constraint. Your design is over-constrained.

Consider the design without any pegs. Just plate on plate contact constrains 3DOF's (translation normal to plane and 2 rotations about in-plane axes). Now consider just one peg in an exactly-sized hole, no bottom plate. This constrains 4 DOF's (2 translations normal to the axis of the peg, and 2 rotations about axes normal to the axis of the peg).

Now combine the two: assemble the two plates with one peg in one hole. You are constraining 5DOF's right? (All but rotation about the axis of the peg). But your total constraints equals 7. Why? It's because you are attempting to constrain 2 rotations (about in-plane axes) twice. This is the definition of over-constraint. Unless you are 100% certain that your peg is perfectly perpendicular to your bottom plate, and that the hole in the top plate is perfectly perpendicular to the top plate, the two plates will be constrained at different rotational positions and will not sit perfectly flat against one another. How can you solve this? What if instead of a cylindrical peg, you use a sphere that is bolted to the bottom plate and has the exact diameter of the hole? Now, the sphere sits in the hole and only constrains 2 translations normal to the axis of the hole, and your total number of constrains is 5, with each constraint having only one constraining feature. This design now follows the principle of exact constraint.

But this really isn’t your problem, because now-a-days we have pretty good machines that are capable of drilling holes very close to perpendicular to a surface, and there’s a pretty good chance that even if you use one peg in one hole, your plates will come together without you being able to notice any angular error. The real problem in your design lies in the fact that you have 4 pegs in 4 holes, all exactly sized. This design is severely over-constrained because you have tried to constrain the 2 in-plane translations 4 times! In the real world of manufacturing tolerances, there is no way you can perfectly guarantee the distance between your pegs and/or holes every time, and your plates will simply not come together. So what can you do?

Consider again the two plates with one peg and one hole (now assuming that we have expensive machines and can use pegs instead of spheres). Again, we have constrained 5 DOF's. Let's add a second peg and a second hole. Now, all 6 DOF's are constrained, but we are now over-constrained in both in-plane translations. If we change one hole to a slot with width equal to the pin diameter, oriented along the line connecting both pins, we allow for error in the position of the pins/holes, and we have also constrained our last DOF. So technically we can stop here (we can use spheres instead of pins if we want to be really thorough).

But your boss insists on having 4 pins on the bottom plate because it “looks nice”. So what do you do? Oversize the last two holes so they do not contact the pins/spheres, offering no additional constraint and keeping the design exactly constrained in all DOF's. See a top view of the top plate below: