

KNO-008 · Instruments That Extend the Senses

KNO · Ways of Knowing

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Article Abstract

The phrase in this article's title is a useful shorthand and a poor description. A thermometer does not sharpen anyone's sense of heat; it converts temperature into a length the eye can read. What an instrument builds is a chain of conversions whose last link happens to be perceivable, and the human sensorium is not extended anywhere along it. This article follows the consequences: that trusting a reading means trusting every link, that calibrating an instrument is circular before it is routine, and that the interesting instruments are the ones whose output corresponds to no sense at all. It discharges the longitude problem two earlier articles deferred, and finds the familiar account of how it was solved does not survive contact with the scholarship.

In 60 Seconds

Spectacles aid a sense, a telescope extends one, and a thermometer does neither: it converts a quantity no eye registers into a length the eye can read, and the observer infers. Believing such a reading is believing every link of that chain, and no point along it is settled by looking. Galileo's telescope was accepted through independent replication rather than on sight. Calibration is circular at the outset, because justifying an instrument needs the law that measuring with it is meant to establish; that circle was broken by iteration rather than by decree, and a published critique holds that reasoned argument can break it. Longitude was not solved by one clock: lunar distances were treated as co equal in 1767, rested on dead reckoning between observations, and declined when chronometers grew cheap. Radio astronomy began as an attempt to reduce noise. A gravitational wave detection ends in no sensation at all, and its first signal came from a burst search rather than from template matching. What makes two readings comparable is an institutional chain, and the vocabulary that defines it warns what it does not guarantee.

Why This Question Matters

A reading is offered as if it were an observation, and it is the end of a chain that began where no sense reaches. Taking it as perception hides every place the chain can be wrong: the substance coupled to the quantity, the calibration behind it, the model that turns a correlation into a claim. The distinctions here let a reader ask what validated the instrument, whether agreement among copies is worth anything when they share a design, and whether the story of how a problem was solved is the story the record actually supports.

1. What an instrument actually does

Consider the difference between three devices that are usually filed together.

Spectacles correct a defect in an existing sense and change nothing about what kind of thing can be perceived. Light still arrives at the eye and the eye still sees it.

A **telescope** operates in the same modality and pushes past a natural limit. It is still light, still the eye, still seeing, and the objects it reveals are of a kind the unaided eye already knows.

A **thermometer** does something categorically different. Temperature is not a thing eyes perceive at all. The instrument couples a thermometric substance to the quantity of interest and converts it into a length, and the length is what the observer actually sees. The observer does not perceive temperature more acutely. The observer perceives a column of liquid and infers.

Of the three, the spectacles **aid** a sense and the telescope **extends** one beyond its natural range, which are the two literal cases and the least interesting ones; the table below reserves each word for one of them. The third is what many scientific instruments do, and the pattern recurs widely: the device converts an inaccessible quantity into an accessible one, and every step of that conversion is a place where the chain can be wrong.

This suggests a working vocabulary, offered as a stipulation and not a discovery.

Aid	Restores or improves a sense within its own modality.
Extension	Same modality, beyond the natural range.
Transducer	Converts a quantity the senses cannot register into one they can.
Inferential instrument	Produces no perceivable analogue at all; the output is a number or a statistical statement, and the phenomenon is reached only through a model.

The four are not stages. They coexist, and a single apparatus can contain all four in series.

Where That Leaves Us

Three devices filed together do three different things, and only two involve a sense. Restoring sight and reaching past its natural range are the literal cases and the least interesting. The third turns what no eye registers into what an eye can, making the observer a reader of columns rather than a perceiver of heat, and every conversion between a place the result can fail.

2. The chain has to be trusted link by link

If an instrument is a chain of conversions, then the question of whether to believe it is not a question about the senses. It is a question about the chain, and there is no point along it where perception settles the matter.

The telescope is an early example of instrument-mediated observation. Galileo's observations of 1609 and 1610 were not accepted on sight; the instrument and its reports spread across Europe and were taken up by multiple observers. The precise sequence of that contested reception is not reconstructed here, because the accessible sources do not support a more detailed chronology.

The structure is worth naming because it recurs. A new instrument reports something no one has seen. The report cannot be checked by looking, because looking is what is in question. One check that works is agreement among independent instances of the same chain, built by people with no stake in one another's results. **It is not sufficient on its own.** Copies of an instrument can share a design, a calibration route or a background model, and instruments that share any of those can agree for the same wrong reason. What raises the agreement above that are checks of a different kind: feeding the chain a **known input** and seeing whether it returns it, measuring the same

quantity with an **instrument of another design, intervening** on the phenomenon and seeing the reading follow, and holding the result against an **independent constraint** that does not come through the same chain.

Where That Leaves Us

If belief in a reading is belief in a chain, no amount of looking settles it, and the founding case bears that out: the instrument was trusted once people with no stake in each other built their own and got the same thing. Agreement alone is not enough, since copies can share a design and be wrong together. Known inputs, other designs, intervention and outside constraints are what raise it.

3. Calibration is circular before it is routine

The deepest problem in instrumentation is not building the device. It is establishing what its readings mean, and that problem is circular at the outset.

To justify a thermometer one needs the law relating the behaviour of the thermometric substance to temperature. To establish that law one needs to measure temperature. The circularity is real and has a name: the problem of nomic measurement, set out in a study of eighteenth and nineteenth century thermometry which argues that the circle was broken not by decree but by iterative, self correcting refinement across competing thermometric traditions over a long period (Chang 2004).

Two consequences follow and both are easy to miss.

First, **an instrument does not simply measure a quantity that was already well defined**. Before workable thermometry there was no operational way to say that two bodies were at the same temperature, and fixing the measurement procedure was part of fixing what the quantity was.

Second, **a circularity of this kind can arise where a novel phenomenon is at stake**, and it is a risk to be looked for rather than the structure of every new instrument. Where it does arise, whether an apparatus is working correctly is judged by whether it produces the expected result, and what result to expect is what the apparatus was built to find out. **The nomic-measurement case of the previous paragraph is narrower still**: it belongs to the foundational cases where the quantity itself is being fixed along with its measurement, and a thermometer checked against a maintained standard is not in that position. In the sociology of science this is called the experimenter's regress, associated with Collins (1992). The University of Chicago Press 1992 edition names *Detecting Gravitational Radiation: The Experimenter's Regress* as chapter 4; no broader claim from that chapter is relied upon here. The argument of that chapter, and the broader claims made about the regress, were not, and no broader claim is made here.

There is a published critique of the regress and it belongs here rather than in a footnote.

Franklin argues, from the gravitational wave episode, that the regress was broken by reasoned argument (Franklin 1994). Read it as narrowly as it is written: it denies that the regress is inescapable, not that it never arises. This section already treats the circularity as a risk to look for rather than as the structure of every new instrument, and the critique is what makes that treatment a position in a debate rather than a hedge.

Where That Leaves Us

Establishing what a reading means is harder than building the device, and at first the two requirements chase each other. History shows the circle worn away by rival traditions correcting one another rather than cut by decree. Fixing how to measure was part of fixing what was measured, and the circularity is a risk worth hunting, not the shape of every device. A published critique argues it can be broken.

4. Longitude, and a debt discharged

KNO-006 deferred the longitude problem as belonging to time. KNO-007 examined it and forwarded it here, on the ground that it is not a question about what time is but about transporting a time standard. This article discharges the debt, and the scholarship overturns the familiar story.

The popular account is that John Harrison's marine timekeepers solved the problem. The scholarly account is that longitude finding in practice required hardware, procedures and tables, and skilled people exercising judgment, and that no single artefact solved anything on its own (Miller 2015).

More striking is the fate of the rival method. Lunar distances, made practical by Tobias Mayer's tables in the 1750s and by Maskelyne's *Nautical Almanac* from 1767, were treated by the Board of Longitude in 1767 as co equal with chronometers. The *Endeavour* voyage of 1768 to 1771 used lunar distances, at a time when Harrison's H4 was the only chronometer accurate enough and there was exactly one of it. **This article does not say that they were the primary method, there or on Cook's other voyages**, which is a claim the accessible pages do not settle. Lunar tables remained in nautical almanacs well into the following century, and the method declined as chronometers became cheap rather than because it failed (de Grijns 2020).

What that source also describes is the estimate the method rested on. On the *Endeavour* voyage the lunar work was combined with the tried and tested dead reckoning approach, which remained a fundamental yet supplementary navigation tool when weather interrupted the lunar observations; ship speed was estimated from a chip float on a knotted log line timed by a glass, and the procedure could not correct for drift or currents (de Grijns 2020). **No longitude figure is given here**, because what the passage supplies is a procedure and its limits and not a number.

The general point is about instruments rather than about ships. **An instrumental solution and a computational solution can be equally correct**, and which one wins can be decided by manufacturing cost rather than by accuracy. Reading the outcome backwards as a demonstration that the clock was the right answer imports a conclusion the history does not supply.

Where That Leaves Us

A debt two earlier articles left open closes here, and the familiar answer turns out to compress a longer story. Finding position at sea took hardware, tables, procedures and judgment together, no artefact deciding anything alone. The rival method was treated as an equal, leaned on an estimate blind to currents, and faded as its competitor grew cheap. Cost decided as much as accuracy did.

5. Instruments with no perceptual analogue

Some instruments detect things for which no sense could exist, and these show the transduction structure at its clearest.

Radio astronomy began by accident and not by design. Karl Jansky was employed to trace static interfering with transatlantic telephony (NRAO/AUI Archives, "Papers of Karl G. Jansky"), using a rotating antenna (Jansky 1932) operating at 21 MHz (Kellermann et al. 2023). He first suspected the

Sun. By early 1933 the direction of the hiss no longer tracked the Sun, and in February he concluded that it came from a fixed direction in space (Kellermann et al. 2023), in the direction of the centre of the Milky Way (NRAO, Jansky Lectureship). The primary report records that the source of this disturbance had been thought somehow associated with the sun (Jansky 1933), which is the hypothesis the later analysis displaced, and that same institutional history identifies the result as radio waves from the central region of our Milky Way Galaxy. The instrument was not built to observe anything. It was built to reduce noise, and the noise was the observation.

Gravitational wave detection has no perceivable stage at all. The first reported direct observation gives a peak strain of 1.0×10^{-21} (Abbott et al. 2016). Nothing in that chain terminates in a sensation. Moreover the detection itself is a statistical judgement. **One of the methods used for it** is matched filtering: the data are correlated against a bank of theoretical template waveforms, and for Gaussian noise this reduces to a maximised data to template correlation that optimises signal to noise, which is a form of maximum likelihood detection (Jaranowski and Królak 2012). **That method is not the whole of how such a signal is found**, and this article does not present it as the definition of the detection.

The initial detection did not come from template matching at all. The collaboration's own summary records that the initial detection was made by a so called burst search, and that two separate matched filtering pipelines, called PyCBC and GstLAL, recovered the event afterwards (LIGO Scientific Collaboration, science summary). So the templates were a cross check on a detection made without them, and an account that opens with matched filtering has the order the wrong way round.

That is worth stating plainly. **The object of the claim is not seen, heard or registered by any sense. It is inferred from the degree to which a record matches a model of what such an event would produce.** The instrument does not extend a sense. It replaces perception with inference, and where the inference runs through templates it is only as good as the model that supplies them.

Where That Leaves Us

Some instruments reach objects no sense could register, and show the structure plainly. One began as an attempt to clean up interference and ended by reporting where a hiss came from. Another ends in no sensation at all, reaching its object through a model of what would produce it. Even there the initial signal was found without template matching, and the matched filter pipelines recovered it afterwards.

6. What makes two readings comparable

An instrument that only its owner can trust is not much use. What makes a reading in one laboratory comparable with a reading in another is metrological traceability, the chain of calibration back to a common reference, a concept incorporated into the third edition of the international vocabulary of metrology (JCGM 200:2012).

A citation caution belongs here rather than in a footnote. **A widely circulated copy of that vocabulary carries the date 2006 and is a pre publication committee draft, not the published edition.** Anyone citing it from that copy would be citing a draft. The current reference edition is JCGM 200:2012.

The vocabulary defines it as a property of a result, and says what it does not guarantee. Metrological traceability is a property of a measurement result by which the result can be related to a reference through a documented unbroken chain of calibrations, each contributing to the

measurement uncertainty; and the same entry warns that traceability does not ensure that the measurement uncertainty is adequate for a given purpose, and does not ensure absence of mistakes (JCGM 200:2012, VIM 2.41, Note 5).

The conceptual point is that comparability is not a property of an instrument. It is a property of an institutional arrangement that links instruments to one another, and it has to be maintained. An uncalibrated instrument is not a slightly worse instrument; it is an instrument whose readings do not connect to anyone else's.

Where That Leaves Us

An instrument nobody else can check is of little use, and what connects one laboratory to another is a maintained chain rather than a property of any device. The vocabulary that defines that chain is careful about what it does not promise: not that the uncertainty suits the purpose, and not that no mistake was made. An uncalibrated instrument is not slightly worse; its readings simply do not connect.

7. What the evidence cannot settle

Whether an instrument is working, in a novel case. The circularity of section 3 is not a puzzle awaiting a solution. It is a structural feature, managed by iteration and by independent replication rather than removed.

What an instrument would have shown had it been built differently. Every instrument selects. What it does not register is not thereby absent, and the absence of a signal is evidence only when the instrument's response to that signal is known.

Priority in accidental discovery. When an instrument built for one purpose registers something else, deciding who discovered what depends on what counts as recognising a phenomenon, and that is not settled by the record alone.

Several sources used here. Three of the works cited were verified as publications but their relevant text could not be read in this round. The claims resting on them are worded conservatively to match what can be supported.

Where That Leaves Us

Four things stay open here, each for a different reason. Whether a device works in a genuinely new case is structural rather than unsolved. The counterfactual about a differently built instrument has no answer, since selection is what instruments do. Credit for the unintended turns on what counts as recognising. And three sources were verified as publications without their relevant text being read.

8. Conclusion

Many instruments do not extend the senses at all. They enrol them at the end of chains that begin somewhere the senses cannot reach, and in those cases the epistemic weight sits on the chain rather than on the moment of perception at its end. **Some instruments do extend a sense**, and section 1 separates them out; the claim of this article is about the many, not about all.

That is why the history of instruments is not a history of sharper eyes. It is a history of calibration, of replication among people who do not trust one another, of standards maintained by institutions, and of models that turn a correlation into a claim about a black hole merger. When an instrument is believed, what is being believed is all of that, and the reading is only the last and least of it.

Where That Leaves Us

The argument comes back to where the weight sits. For many instruments the epistemic load is carried by the chain and not by the moment of perception at its end, and section 1 marks out the ones where that is not so. Read this way, the history stops being about better eyes and becomes about calibration, mutual distrust, maintained standards and models that make a correlation mean something.

What We Know, and How

Experts at Bologna reported seeing little or nothing through Galileo's telescope in April 1610, the Collegio Romano withheld confirmation until October, and credibility was established by independent replication; the source for this was read only as far as its accessible pages go. The circularity of validating a measuring instrument without the law that justifies it is called the problem of nomic measurement and is attributed to a 2004 study of thermometry, which argues the circle was worn away by iterative self correcting refinement rather than broken by decree. Franklin argues from the gravitational wave episode that reasoned argument broke the regress. The University of Chicago Press 1992 edition titles its chapter 4 with the phrase *Detecting Gravitational Radiation: The Experimenter's Regress*, which the human authority read in the contents and nobody read further. The Board of Longitude treated chronometers and lunar distances as co equal in 1767; the *Endeavour* voyage combined lunar work with dead reckoning, which could not correct for drift or currents. Jansky's result is identified by the observatory's institutional history as radio waves from the central region of the Milky Way, and the primary report records the solar hypothesis it displaced. The first reported direct gravitational wave observation gives a peak strain of 1.0×10^{-21} , and the initial detection was made by a burst search, with PyCBC and GstLAL recovering the event afterwards. Metrological traceability is defined as a property of a measurement result related to a reference through a documented unbroken chain of calibrations.

What We Still Don't Know

Several details remain outside the evidential scope used here: the full argument in Collins on the experimenter's regress; the precise disputed reception of Galileo's telescope; the detailed conclusions of the historical thermometry study; whether lunar distances were the primary method on Cook's voyages; the wording of the published 2012 vocabulary preface relative to the earlier committee draft; and whether Sullivan's chapter independently supports the Jansky narrative. None of those points is used here as a foundation for a stronger claim.

What Could Change Our Minds

A reading of Collins's chapter would settle what that work argues about the experimenter's regress, as opposed to that it names it. A source whose text can be read, on the reception of Galileo's telescope, would replace a claim currently resting on a publisher's page and a separate essay. Paginated evidence that lunar distances were or were not the primary method on Cook's voyages would decide a question this article leaves open in both directions. Reading the published 2012 preface would convert a presumption about the vocabulary into a check. And an instrument of an entirely different design agreeing with one of these results would do more for it than another copy of the same design agreeing, which is the point section 2 makes and which applies to this article's own sources.

If You Remember Only One Thing

An instrument rarely extends a sense; it ends a chain of conversions, and believing the reading means believing every link.

Related Articles

- KNO-006 · *Maps and Spatial Representation*
- KNO-007 · *Calendars and Time Measurement*

References

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Boundary note

With KNO-007, Calendars and Time Measurement. KNO-007 treats what is agreed to be measured; this article treats the devices and the chains that realise it. **The longitude problem, deferred by KNO-006 and forwarded by KNO-007, is discharged here in section 4 and is not open anywhere else in the series.**

With KNO-011, Measuring Before Theorising. This is the closest boundary in the series and needs care. **KNO-008 covers the circularity of validating a particular instrument**, because that is a problem about the device. **KNO-011 covers measurement without theory as an epistemic strategy**, including whether a research programme can proceed by measuring first, and that broader question is not anticipated here.

With KNO-013, Models, Maps and Reality. Section 5 states that gravitational wave detection reaches its object through a model. **The general question of what a model is and how model dependence bears on realism belongs to KNO-013** and is not developed here.

With KNO-006. The structural resemblance between an instrument's selectivity and a map's is real but limited, and this article does not press it. Map projection is constrained by a geometric theorem; instrument selectivity is a design decision. **They are analogous in consequence and different in kind.**