

Supplemental Note 1: “Kepler screwdriver” assembly

Assembly of the Kepler screwdriver, or simply *Kepler driver* does not require extra steps to post-process the 3D printed pieces such as drilling or sanding. It also does not require any fastenings to put together. However, we do recommend lubricating the planetary gears before putting the device together completely. We provide instructions on this within this assembly guide. Because this device is 3D printed, one may expect small imperfections on the components brought up by the printing process to cause minor issues in the device’s functionality. This can be resolved with repeated use of the device until movement of the components becomes smoother over time.

Printing the Kepler driver components

It is recommended that every component is printed using an SLA printer (photopolymer resin printer) at a high resolution (for example 0.005 mm layer height) to ensure that component dimensions are as close to the designed dimensions as possible. FDM printers may not be able to offer this resolution and, because of the nature of the printing technique, may introduce imperfections that might interfere with the device’s operation.

We were able to successfully print and assemble several Kepler drivers and replacement parts using a Formlabs Form 3 and Clear V4 resin (**see supplemental note 4 ‘Materials and sourcing’ under section ‘3D printer and accessories’**). A different resin which offers good resolution may be used instead if desired, however this was not tested by us. Keep in mind that Clear V4 resin is relatively brittle and may break if the device is dropped but will withstand regular day-to-day use under normal conditions. Finally, because Clear V4 resin has the tendency to deform during post-curing when prints are not very dense, we recommend not doing a post-cure; instead, simply washing the screwdriver components and letting them cure at room temperature over time (may take up to 7 days) will ensure that the shape of the components is preserved.

All Kepler driver components are available as STL files in our GitHub repository (<https://github.com/rjibanezalcala/EXPLORE>). Pre-made Preform (**see supplemental note 4 ‘Materials and sourcing’ under section ‘Software’**) projects are also provided in the same repository for downloading and printing directly. The components list is shown below (**Table S1.1, Fig. S1.1**), which indicates what components are needed and how many of them to print. Note that the addition of the counter module is optional, however we recommend adding it as it counts the number of turns made at the input which can reduce user error. If the counter module is added, make sure you make the replacements indicated in **Table S1.1**. This list can also be found in **Supplemental Note 4**.

“Kepler” screwdriver	Bottom casing	1
	Bottom casing shell	1

printable components	Knob (small or large)*	1
	Bit adapter	1
	Middle indicator	1
	Top casing	1
	Top casing shell**	1
	Carrier	2
	Carrier spacer	2
	Planet gear	6
	Planet gear spacer	6
	Sun gear shaft***	1
	Sun gear socket	1
	Sun spacer	2
	Ring gear	2
	Counter ring gear (optional)	1
	Counter carrier (optional)	1
	Counter carrier spacer (opt.)	1
	Counter planet gear (opt.)	3
	Counter planet gear spacer (opt.)	3
	Counter sun gear (opt.)	1
	Counter sun gear spacer (opt.)	1
	Counter knob (opt.)* <i>Replaces regular knob</i>	1
	Sun gear shaft adapter for counter (opt.)*** <i>Replaces one regular sun gear</i>	1

	Counter face (opt.)	1
	Counter shell (opt.)	1
	Top casing shell for counter module (opt.)** <i>Replaces regular top shell</i>	1

Table S1.1 | Kepler driver components list. This table shows all the 3D printable components necessary to assemble the Kepler driver. Counter components (marked as optional) are not required to use the Kepler driver; however, the counter module does provide some readability to the device and is recommended. Items marked with “*” indicate that one may replace the other if the counter module is to be used. Thus, if the counter module is added, print the *top casing shell for counter module* instead of the regular *top casing shell* and the *sun gear shaft adapter for counter* instead of the regular *sun gear shaft*. All listed components can be found in our GitHub repository at <https://github.com/rjibanezalcala/EXPLORE/tree/main/KEPLER>.

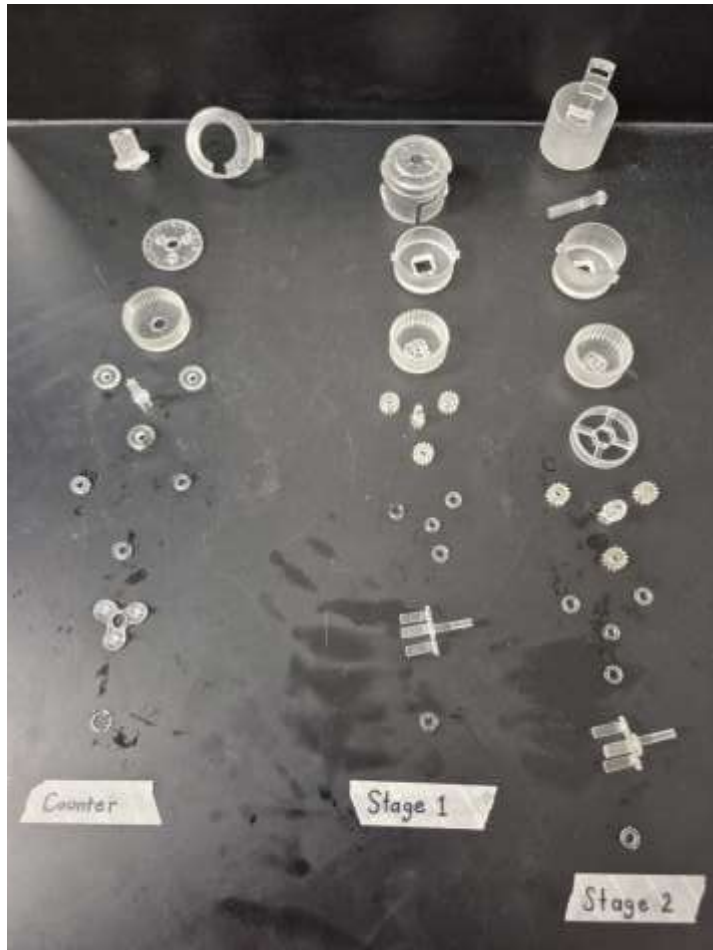


Figure S1.1 | Kepler components. The photograph shows all the Kepler driver components classified by what subsystem of the device they belong to. The top components encompass the outer part of the device (shell) and the inner components are toward the bottom.

In summary:

- a. Print Kepler driver components using an SLA printer with high-resolution compatible resin (this type of resin tends to be runnier) at a resolution of at least 0.005 mm layer height.
- b. Do not post-cure the Kepler driver components, instead simply wash them and let them cure at room temperature for a few days. If post-curing is still desired, we recommend limiting the cure time.
- c. All 3D printable components can be found alongside ready-to-print Preform projects at <https://github.com/rjibanezalcala/EXPLORE/tree/main/KEPLER>.
- d. The components list and quantities are listed above in **Table S1.1** or also under “Kepler” screwdriver printable components’ in **supplemental note 4**.

Assembling the planetary gear systems

Relevant components (screwdriver):

- Sun gear (shaft, and socket), 1 each.
 - Replace sun gear (shaft) with sun gear shaft adapter for counter if printing a counter module.
- Sun gear spacer (regular), total of 2.
- Planet gears (regular), total of 6.
- Planet gear spacers (regular), total of 6.
- Ring gear (regular), total of 2.
- Gear carrier (regular), total of 2.
- Gear carrier spacer (regular), total of 2.
- Middle indicator, total of 1.

The main planetary gear systems

The instructions below assume only the components listed under “Relevant components (screwdriver)” (**Fig. S1.2a**).

1. Slide a sun gear spacer into the middle peg on each carrier. Then, slide one planet gear spacer into the three surrounding pegs (**Fig. S1.2b**).
2. Place a sun gear (shaft and socket) in the centre peg on each carrier (**Fig. S1.2c**), and one planet gear into each of the surrounding pegs (**Fig. S1.2d**). Wiggle the sun gear a bit if this gives you trouble.
3. Slide a carrier spacer on the bottom side of the carrier (on the longer shaft side (**Fig. S1.2e**), then slide the whole assembly into a ring gear (**Fig. S1.2f**). Repeat for the other carrier and ring gear.
4. Test the planetary gear systems by turning the sun gear in both directions. Lubricate the gears as needed.
5. Make sure to take note which one has the sun gear shaft, and which one has the sun gear socket and middle indicator, the former will be the stage 1 gear system, and the latter will be stage 2.
6. On the stage 2 gear system, slide the middle indicator piece onto the sun gear socket so that it sits on top of the whole gear system (**Fig. S1.2g**).
7. Set both gear systems aside for now (**Fig. S1.2h**).

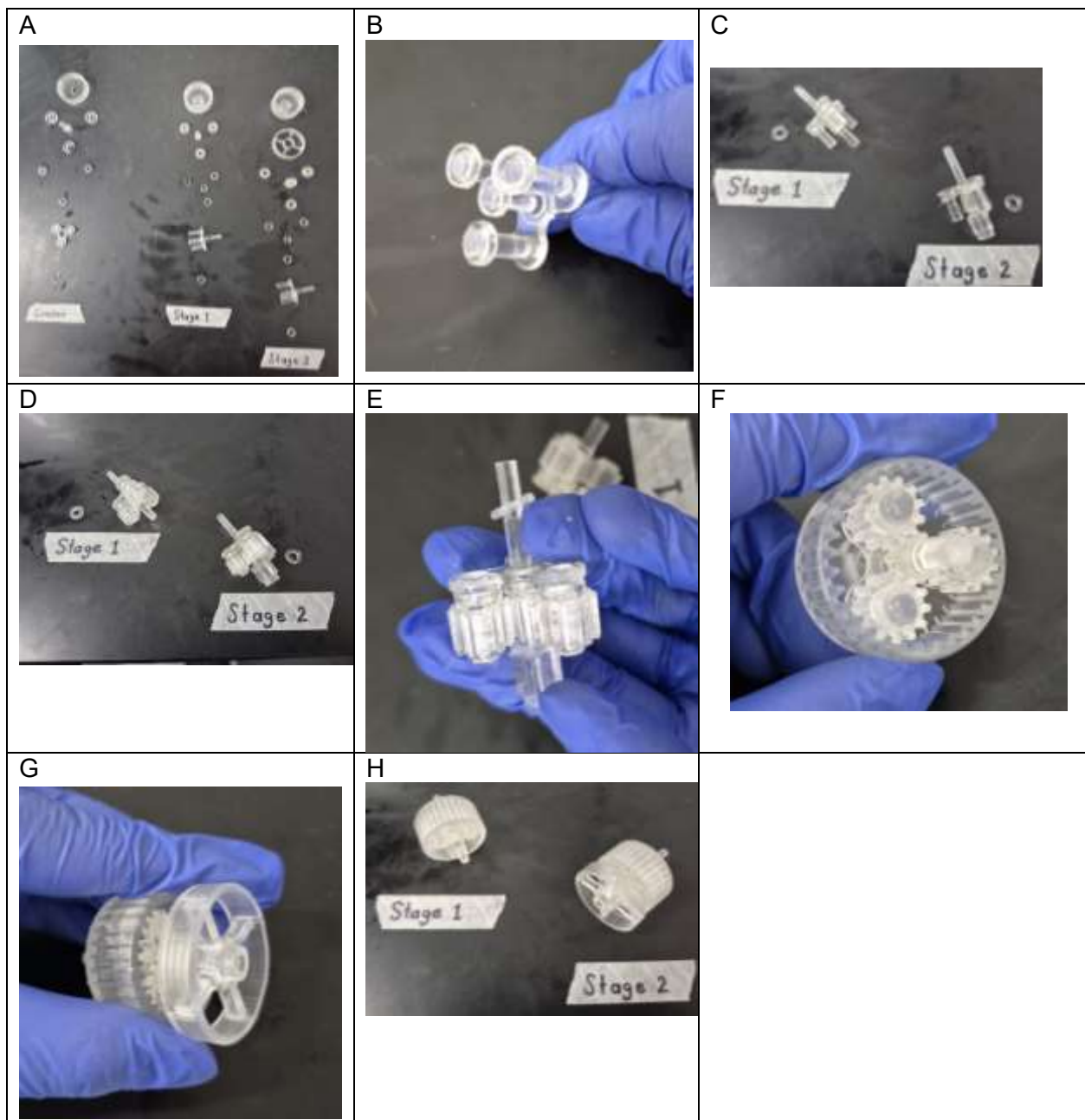


Figure S1.2 | Stage 1 and 2 gear systems assembly. **a.** Gear system components, separated by the subsystem they belong to. **b.** Placing the sun (middle) and planet gear spacers on the carrier. **c.** Placing the sun gears on the carriers. Stage 1 requires the sun gear shaft and Stage two the sun gear socket. Carrier spacer pictures off to the side of each carrier. **d.** Placement of the planet gears around the sun gear on the carrier. **e.** Placement of the carrier spacer on the bottom side of the carrier. **f.** Placement of the carrier assembly within the ring gear, completing Stage 1. **g.** Placement of the middle indicator on top of Stage 2's sun gear. **h.** Comparison between Stage 1 and Stage 2 gear systems.

The counter module

Relevant components:

- Sun gear shaft adapter (counter)
- Sun gear spacers (counter)
- Planet gears (counter)
- Planet gear spacers (counter)
- Ring gear (counter)
- Counter module planetary gear system
- Counter face
- Counter shell
- Counter knob

The counter planetary gear system

Follow steps 1 through 5 from the main planetary gear systems to construct the counter's planetary gear system (see 'Assembling the planetary gear systems', Fig. S1.3a-d).

Assembly

1. Place the counter face piece face up on top of the carrier pegs. Make sure that the pegs slot into place on the bottom of the counter face (**Fig. S1.3e**).
2. Hold the gear assembly by the side pegs on the ring gear and insert the whole assembly face-up into the counter shell, by aligning the side pegs to the small notches on the shell.
3. Push the gear assembly all the way up inside the shell, then twist it to follow the notches until everything clicks into place (**Fig. S1.3f**). The gear assembly should not rotate within the shell if it has been inserted correctly.
4. Insert the knob into place on top of the counter module assembly and rotate the gear system until the '0' marking aligns with the small arrow on top of the "number window", then re-insert the knob so that the '0.00' marking is on top (**Fig. S1.3g, h**).
5. Firmly push down on the knob so that it somewhat stays in place. The knob may fall out as there is no fastening which holds it in place.
6. Set the counter module aside (**Fig. S1.3i**).

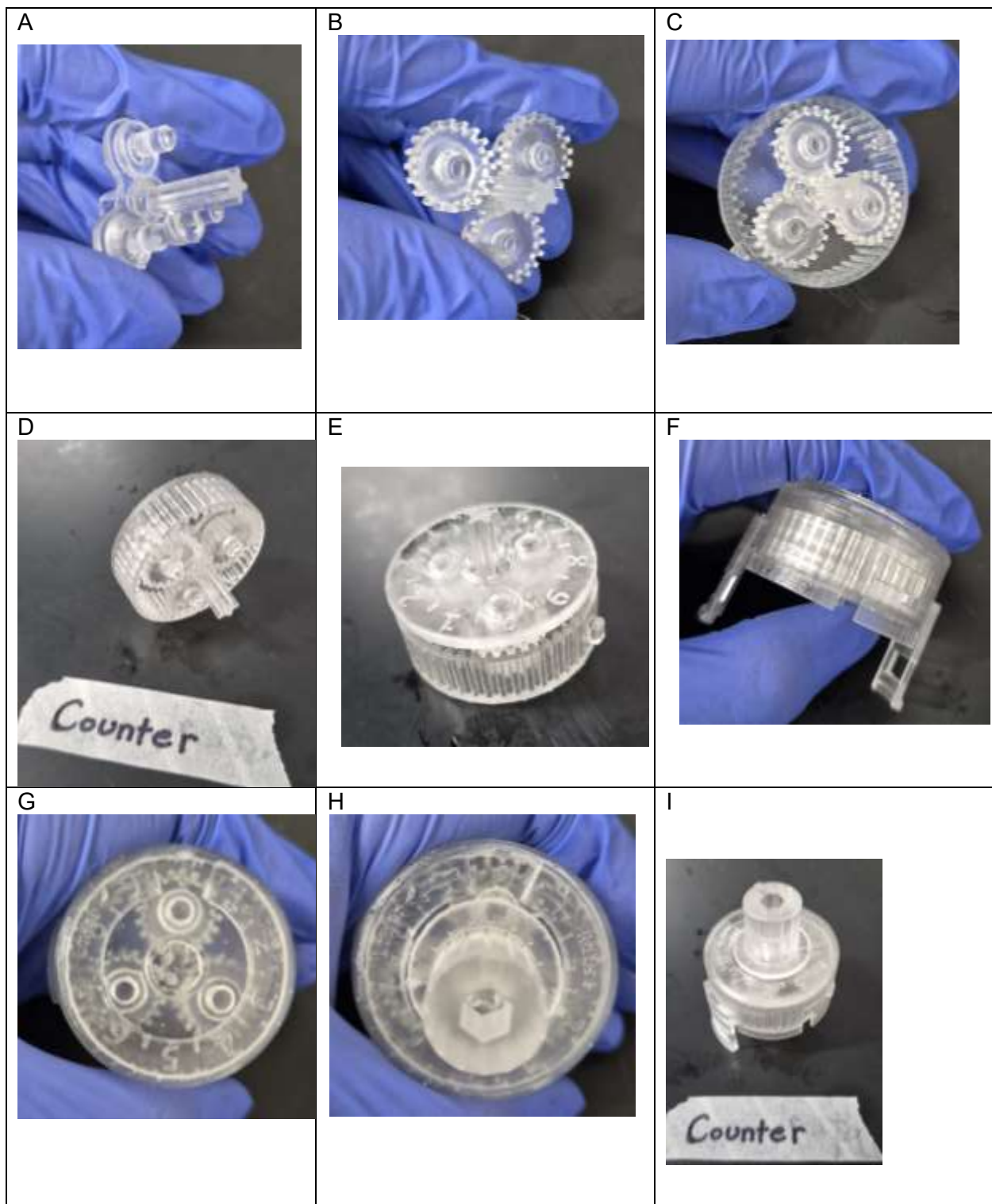


Figure S1.3 | Counter module subsystem assembly. **a.** Placement of planet spacers, sun spacer, and sun gear on counter carrier. **b.** Placement of counter planet gears on the carrier. **c.** Placement of carrier assembly inside of the counter's ring gear. **d.** Finished counter module gear system. **e.** Placement of the counter face on top of the carrier pegs. **f.** Sliding the counter gear system and face into its shell by aligning the pegs on the ring gear to the notches on the shell.

shell. **g**, **h**. Setting the counter system to zero (**g**) before placing the knob on top, also centred at 0 (**h**). **i**. Finished counter module.

The screwdriver body

Relevant materials:

- Knob (small or large), x1 (if not using the counter module)
- Top casing shell, x1 (if not using the counter module)
 - If using counter module, replace with the top casing shell for counter module
- Top casing, x1
- Bottom casing shell, x1
- Bottom casing, x1
- Bit adapter

Assembly instructions:

1. Insert the stage 1 planetary gear system (see 'assembling the planetary gear systems') into the top casing piece, and the stage 2 system into the bottom casing (**Fig. 1.4a, b**). Make sure you align the bottom of the ring gears to the patterns on both the casings so that the whole assembly slides fully into place.
2. Slide the bit adapter into the bottom casing shell from the inside (**Fig. 1.4c**). The bit adapter should not fall out when the shell is held right-side-up (the rat logo on the side should be right-side-up, **Fig. 1.4d**).
3. Slide the stage 1 gear system and bottom casing down the bottom casing shell so that the side pegs on the bottom casing go through the shell notches, twisting until everything slides into place (**Fig. 1.4e**). Set it aside.
4. Slide the stage 2 gear system and top casing in the same way (**Fig. 1.4f**).
5. Align the bottom shaft on the stage one gear system into the sun gear socket on the stage 2 system, then slide everything into place. Make sure that the side latches on sides of the two shells latch together (**Fig. 1.4g**).
 - a. If a counter module is used, repeat this with the top latches on the top casing shell (**Fig. 1.4h**).
 - b. If a counter module is not used, inset the regular knob on the top of the screwdriver.
6. Give the completed screwdriver a few turns to test if everything turns as it should.
7. Slide a 4 mm screwdriver bit into the bit adapter to use the Kepler driver (**Fig. 1.4i**).

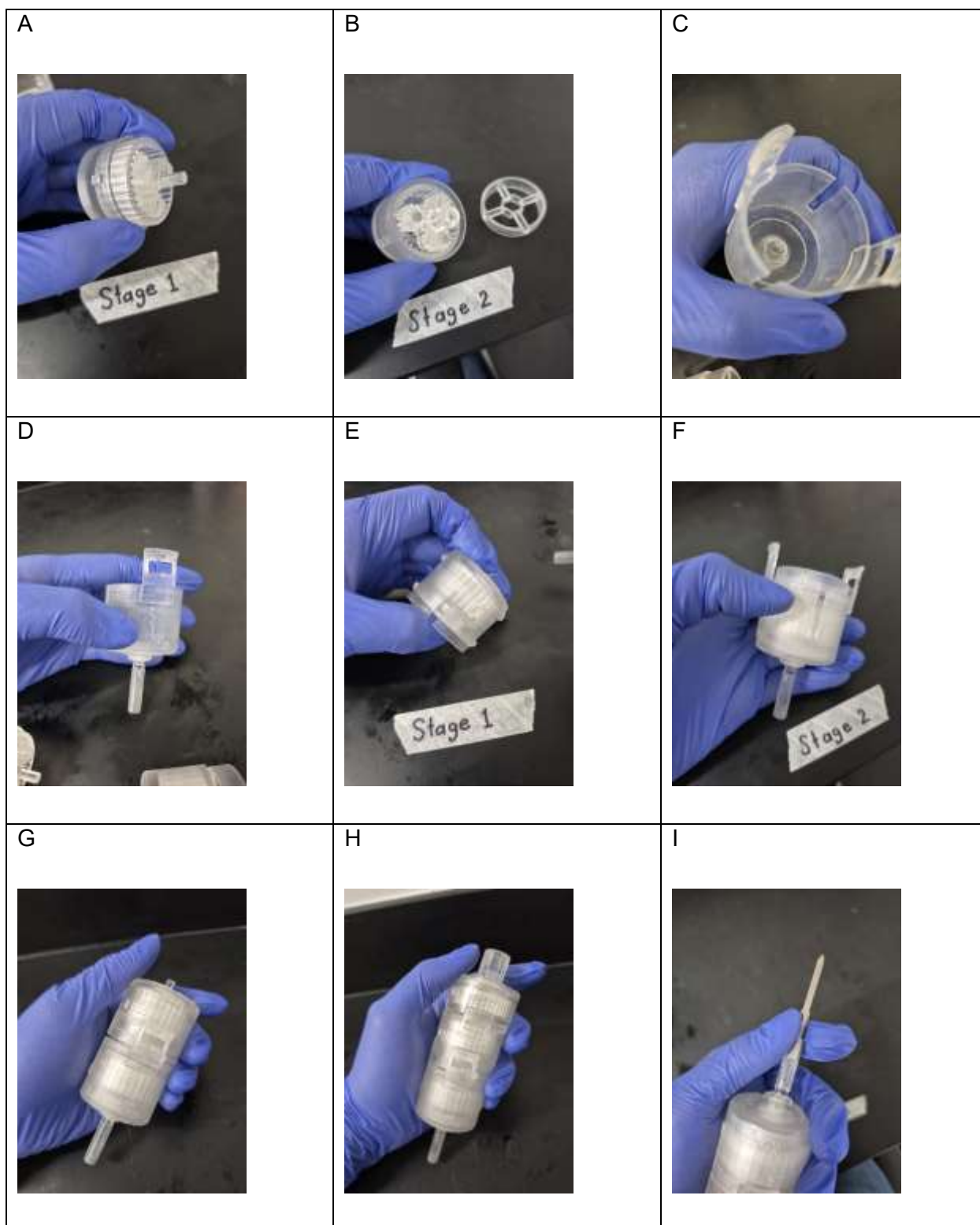


Figure S1.4 | Assembling the Kepler driver. **a, b.** Inserting the Stage 1 gear system into the top casing (**a**) and the Stage 2 gear into the bottom casing (**b**). **c, d.** Inserting the bit adapter piece into the bottom casing shell (**c**). The bit adapter stays in place inside the bottom casing shell if placed correctly (**d**). **e, f.** Inserting the Stage 1 (**e**) and Stage 2 (**f**) gear assemblies into their respective shells. **g.** Mating of the Stage 1 and Stage 2 gear assemblies by snapping their

shells together. The latches on the side hold the two modules together. **h.** Mating the counter module to the rest of the Kepler driver. **i.** Fitting a 4 mm hex screwdriver bit into the bit adapter.