Teacher.solar :: open source/hardware toolbox for CO2-neutral outdoor digital education :: Closing report

Daniel Devatman Hromada[1]

Abstract: The original intention behind the project 'Teacher.solar :: open source/hardware toolbox for CO2-neutral online outdoor teaching' was to design and test a CO2-neutral educational artifact using E-ink technology, as well as the associated software environment for Outdoor Digital Education (ODE) [2]. The ultimate goal was to ensure, through the transfer of knowledge from teachers to students, that the students would be able to construct their own ODE-compliant devices after completing the course.

Three different seminars directly related to the project took place in the summer semesters of 2021 and 2022. Two of them were related to the production of outdoor online artifacts, while the third was more connected to their use and application in the context of a real outdoor seminar. The latter, summarized under the curricular series "Bildung Biodigitale", led to the development of the concept of "eco-artificial education".

Although the goal of developing a 'full solarity' teacher-student hardware/software suite and then transferring this competence to the students was not achieved, interesting results were obtained within the project. The 'teacher.js' software suite for low-bandwidth ODE is fully functional, has been presented at several conferences both in Germany and abroad, and its source code is publicly available on GitHub. Over the course of the curriculum, many interesting solar-powered artifacts were created, some by me, some by my assistants, and some by the students themselves. It was demonstrated that a colored E-ink setup with a WiFi-equipped microcontroller can be directly powered by a solar panel. A prototype of a solar-powered, supercapacitor-buffered, battery-free Bluetooth speaker is still fully functional three years after its conception. The Matrix protocol has proven to be a very interesting means to provide asynchronous classrooms for the communication within both globally or even locally on-line groups.

Keywords: Outdoor Digital Education; teacher.js; solar-powered artefacts; Matrix protocol; Raspberry Pi; Arduino Nano Connect RP2040; super-capacitors; Solarpunk; locally on-line learning; eco-artificial education

[1] Faculty of Design of Berlin University of the Arts (dh at udk-berlin dot de)

[2] In our project proposal we used terms outdoor-online-teaching (OOT) and outdoor-online-learning (OOL). For the purpose of this closing report, these terms will be replaced the term of "outdoor digital education" (ODE) which subsumes both OOL and OOT.

1 Intention

Within the framework of the project "Teacher.solar :: open source/hardware toolbox for CO2-neutral online outdoor teaching,Ï wanted to design and test a CO2-neutral computer tablet with E-Ink technology as well as the corresponding software environment for outdoor online teaching (ODE). This setup was intended to be the sole medium with which I wanted to teach my seminar "Design and Use of a Solar-Powered Online Educational Artifactïn the summer of 2021. The embedded system, based on the Raspberry Pi architecture with adapted open-source software, was supposed to enable me to teach öutdoors."

The ultimate goal was to ensure, through the transfer of knowledge from teachers to pupils/students using the technology, that the pupils/students would be able to construct their own teaching devices after completing the course. I placed particular emphasis on the availability and sustainability of the developed devices: All components should be exchangeable, freely available, and thus ideally replaceable by the pupils/students themselves.

Regarding the software, I wanted to use open-source solutions like BigBlueButton or the Matrix protocol, or to develop my own solutions to ensure a decentralized and self-organized online learning experience for the pupils/students. As a Stifterverband Fellow, I hoped to be able to move from the state of experiments in art didactics to the creation of a teacher.solar community, i.e., a community of teachers and learners who would be interested in exploring the possibilities and limits of ODE.

2 Context

Research, development and teaching took place at Berlin University of the Arts - biggest public art university in Europe. More concretely, it took place at Faculty of Design from which most course participants originated, notably from study programs Art and Media, Visual Communication and Design and Computation. However, colleagues from other departments - e.g. prof. Kirsten Reese from UdK's sound studies department or realisators of UdK's main innovation project Innovationen in Künstlerische Lehre (InKüLe) - were also involved in the process.

Time-wise, the year - 2021 - when main work on the project should have take place was still perturbed by CoVid-19 pandemics. To avoid any disruptions by a possible lock-down, the Summer Semester 2021 course Gestaltung und Einsatz eines solarbetriebenen Online-Bildungsartefakts: Sound und Klang couldn't have a form of a classical seminar taking place on a weekly basis, but had a form of block-seminar which took place in UdK's Berlin Open Lab. Being located on the ground floor with direct access to garden-like outdoor environment, Berlin Open

Lab turned out to be a good location choice providing both in- and out- door teaching possibilities.

A "UdK summer school" course was also planned for August 2021, unfortunately, this had to be canceled due to CoVid-related travel restrictions reducing the number of participants below five. Thus, another ODE didactic took place in Summer Semester 2022 when two courses took place.

3 Finance use

teacher.solar project was officially started in May 2021 with overall budget of 25000 eur awarded by Stifterverband in context of their Senior Fellowships for Innovations in High School Education. From these funds, 11800 eur provided the salary for scientific assistant Mr. Frederic Brodbeck whose principal task was to develop, debug and deploy the software suite teacher.js; 7815 eur was funded the work contract with electro-engineer Mr. Nikoloz Kapanadze who was charged with design, making and testing of all hardware components - notably the supercapacitor driven PCB; with 2700 eur was funded the student assistant contract with Ms. Jung Hsu who helped during the seminars and remaining 2685 eur were invested into acquisition of off-the-shelf components (solar panels, super-capacitors, Raspberry Pis, e-ink displays, microcontrollers, MPPT modules etc.)

4 Courses

Within the core project Laufzeit (2021-2022), concepts and tools developped in direct relation to teacher.solar project shaped three different courses. Given their direct connection to solar energy and outdoor teaching, courses took place only in Summer Semester. Here, we provide a brief overview.

4.1 Summer semester 2021: Design and Deployment of solar-powered artefact: Sound & Klang

As already indicated in the "Context" section, the teacher.solar project has been initiated with the block seminar which took place the week before solar solstice 2022 in indoor and outdoor spaces attached to UdK's Berlin Open Lab (BOL). In spring 2021, the course was preceded by preparatory steps including:

- preparation of the core prototype of "teacher.js" suite (Brodbeck)

- activation of the "teacher artefact" Magic Wand 0 (MW0) where, on Raspberry Pi 4, all ODE software components (teacher.js, Kastalia KMS, Janus, Matrix Synapse) have been installed (Hromada)
- configuration of the portable server 1.teacher.solar on MW0 by means of GSM4 module coupled with the static IP
- prototyping of batteryless, supercapacitor-driven audio microcontroller
- preparation of the didactic concept behind first outdoor online teaching course, with thematic focus being put on sound art (Hromada & Prof. Kerstin Reese (New Music & Sound Art Composition))

Having all necessary software tools installed on the portable teacher server, course started on Monday with introduction of students into the main tenets of the teacher.solar project (e.g. "full solarity", "batteryless digital artefacts" etc.). From second day onwards, students started to develop their own solar-powered, sound-generating artefacts. Student group (N=9) was mostly composed of bachelor students of study program Visual Communication and Absolvent students of study program Art & Media. On different days, teaching was assisted by prof. Reese, Mr. Kapanadze or Mr.Brodbeck.

During the course, one of the students proposed to present the emerging artefacts within the upcoming festival "48-Stunden Neukölln". This has been accepted and indeed realized by the nascent student community which labeled itself as "UdK Solarpunks". From that onwards, focus on the student group was on creation of sound-generating artefacts powered solely by sunlight. Students divided into multiple artefact-specific groups. Communication between groups took place by means of teacher.js software and its "command-casting" [3] software: audio was broadcasted to and from all devices - mostly student's smartphones - connected to 1.teacher.solar node running on MW0 artefact; presentations folios were also broadcasted to student viewports by same means.

Soldering and programming took place within the indoor space of BOL and testing and evaluation of artefacts took place outdoor. Given the weather - sky was cloudless and air temperature exceeded 30 degrees during practically whole day - lack of solar energy was not the issue, rather the contrary: students often needed to go indoor to avoid dehydratation and getting sun-burnt.

Ultimately, after rehearsal at UdK's Medienhaus on Saturday, course culminated with the performance of "UdK Solarpunks" at the Festival. Asides different sound-wave generating artefacts powered solely by the solar energy, performance consisted of decentralized reading of "Solarpunk manifesto" [Th14] broadcasted to 1.te-

[3] Note that in previous publications we used the term "code-casting" where we now use a somewhat more appropriate term "command-casting".

acher.solar Raspberry Pi node running on the Magic Wand 0 artefact which was further streaming the collective output audio to a course-made, solar-powered, batteryless, supercapacitor-driven bluetooth speaker. Considering the reaction of the audience, the seminar was a success.

Abb. 1: Participants of the 0th teacher.solar block-seminar and their solar-driven artefacts and music instruments performing as "UdK Solarpunksť at the festival 48hours Neukölln.

4.2 SoSe 2022: Bildung Biodigitale 1 - Plants, Herbs and Weeds

Bildung Biodigitale is a curricular series topically located on a somewhat neglected disciplinar border between informatics, didactics and biology. The zeroth (0th) Bildung Biodigitale (BB) seminar took place during the first CoVid semester (summer semester 2020) carried the title "Of organic and digital trees" and with more than 40 participants was my most followed on-line lecture series [4].

In summer semester 2022, finally continued without CoVid related restrictions. Teaching took place in different gardens and parks and often involved peripatetic (e.g. walking around) component. UdKs tradition of Pflanzenkunde has been followed, Goethe's theory of botanical forms has been discussed and students were

[4] Note that art University like UdK is an institution where master-apprentice approach to teaching is still cherished and median seminar size is cca 4-5 students.

Abb. 2: Students working together on a "draw the plantöutdoor assignment. Analogue pencil and paper tools are prefered over e-ink tablet and stylus ones.

asked to apply classical philosophical method of "phenomenological reduction"to establish direct contact with the realm of herbal essences. Plant-identification apps like Naturblick or PlantNet helped with plant identification. Plant holograms were created and aetheric were distilled out of Artemisia Vulgaris. Online teaching tool teacher.js embedded on the Magic Wand 0 artefact was used and tested exhaustively to provide connectivity between teacher and student e-ink tablet and smartphone devices.

Seminar culminated with its last session which took place in Berlin's main Botanic Garden where, in garden's Arzneipflanzengarten section, students could use nothing else than their voice to get further information about specific plant species growing directly in front of their eyes. Thus, the notion of ODE has been not only combined with the notion of locally online learning, but also with speech-recognizing artificially intelligent system running on the edge-computing device.

More information here: https://www.inkuele.de/dokumentation/details/bildung-biodigitale, here https://gardens.digital and in seminar's publicly available and federatable matrix room. [5]

Abb. 3: Remaining participants of the 1st Bildung Biodigitale course one hour after the course officially ended and two hours after feasibility of locally online ODE involving edge-computing AIs has been demonstrated.

Abb. 4: Experiments with solar soldering in the garden colony "Dreieck Nord off-the-grid and without battery.

4.3 SoSe 2022: Design and deployment of outdoor digital education artefacts

The goal of the hands-on, making seminar was to continue developing the themes introduced a year ago and deepen student's ability to build, make, program and optimize solar-powered digital artefacts. Main topics which were discussed were: SSolar energy, Photovoltaics, Microcontrollers of 2nd generation (Daisy Seed, RP2040, Arduino Nano Connect), supercapacitors, E-ink, Machine Learning, TensorFlow Lite, digital gardening and even embedding artificially intelligent systems into garden dfwarfs". Applied methods were Outdoor On-Line Teaching, Collaborative making, up-cycling, coding and soldering - including experiments with soldering powered solely by solar energy.

It was mostly students of study program Art and Media who participated in the Wahlpflicht seminar. The seminar took place on a bi-weekly basis and initially followed the theoretical Bildung Biodigitale seminar. Thus, the fact that BB was a semi-peripatetic seminar happening on different places had a direct impact on the Design and deployment course. This turned out to be sub-optimal because contrary to BB course where all equipment could be easily brought along, the procrss of making and prototyping often necessitates having equipment - e.g. soldering lots - installed and ready. Therefore, while the original tentatives to realize the making seminar in an agreeable setting of a Kleingarten led to innovative results and insights - e.g. solar soldering - the seminar group had ultimately decided to realize last few sessions of the seminar in a more conservative setting of Berlin Open Lab and UdK's Medienhaus.

The major success of the seminar was the realisation that under good sun-light conditions, 1 Watt solar panel provides enough power for a well-programmed Arduino RP2040 Nano Connect microcontroller to connect to WiFi, download visual content and display it on a WaveShare 7-color E-ink display. Thus, not only a batteryless, but even supercap-less student-terminal can be created from easy-to-get off-the-shelf components which fulfills its task of displaying content from teacher's console to a student's console.

Student works issued from both SoSe2022 courses were presented at UdK's Rungang 2022.

[5] In Your Matrix client, type: /join #edu-botanics:m3x.baumhaus.digital and press enter.

5 Research, Development, Experimentation

Being a multi-faceted enterprise, Research, Development and Experimentation was, within the scope of teacher.solar project - realized along three axes in the same time: hardware axis, software axis, communication axis and didactic axis.

5.1 Didactic axis

The main "didactic innovation" of the teacher.solar project consists in something which is actually not innovation at all but rather a response to fundamental need of our Vitamin-D-synthesizing bodies and circadian minds: to think and learn in environment filled with sun-light and fresh air. Consider as normal in many a society - from indigenous communities to ancient Greeks - outdoor education, "peripatetic learning", "Lernspaziergang" method etc. have been proven to be both educationally efficient and agreeable so many times that it's very difficult to understand why outdoor education is considered to be an exception rather than a rule.

In fact, the only difficulties related to " outdoor education" are:

- weather uncertainty
- presence of environmental / ambient noise
- access to indoor-bound equipment and infrastructure

The third difficulty will be addressed in the section " Lessons learned - What didn't work ".

The second difficulty can be addressed be an appropriate choice of location - parks and gardens turned out to be places where distraction by ambient noise can be significantly reduced. The "weather uncertainty" is slightly more difficult to tackle: here, having an indoor or digital space providing plan B is recommended. As the luck would have it, during three seminars described above, it happened only twice that the course had to be placed indoors due to strong rain.

Ultimately, executing learning and teaching in spaces where other non-human lifeforms can be encountered - be it plants, trees, birds or butterflies - seems to be a factor which has positive impact of student's perception of the seminar. Additionally, creation of a sort of " Temporary Autonomous Zone" which is under control of the teacher-student community also tends to be bring forth positive implications. Thus, when doing internal evaluation among the students and asking the question " Rank all spaces we visited according to Your preference ", all students who attended the session in my " Kleingarten " unanimously ranked the venue to highest rank.

5.2 Communication axis

Since CoVid-19, it is more and more common to use chat applications like Discord, Signal, Rocketchat or Slack to create "asynchronous rooms" wherein teacher and students can communicate both during the seminar as well as between sessions. Among plethora of potential " platforms ", teacher.solar project put all bets on technology called "Matrix" which is actually more than an app. Rather, it is a protocol allowing anyone with basic IT skills to add his/her own " homeserver " to ever-growing federated network of other homeservers.

Within the teacher.solar project, the possibilities provided by decentralized, federated Matrix protocol were pushed to the limit by act of running a full-fledged Matrix node on a portable server. Attached to the artefact " Magic Wand 0 " I was literally carrying the server with me. Additionally, the Raspberry Pi microcomputer on which the server was running was tuned in such a manner that a choice between globally on-line and locally on-line mode was possible.

5.2.1 Globally on-line mode

In globally on-line mode, the microcomputer attached to MW0 artefact behaved like an ordinary Internet server. This was possible thanks to finding a telephone company able to associate static IP address to the SIM-card inserted into the Raspberry Pi's GSM module. In globally on-line mode, students who didn't make it to the garden or a park could connec to the server - physically located in the garden or the park - from their homes or other side of the planet.

Additionally, in the globally on-line mode, all interactions happening within the asynchronous course-related rooms are automatically propagated to other Matrix homeservers with which those rooms are federated.

5.2.2 Locally on-line mode

Having a globally accessible static IP is not always granted, nor is Internet access. One can also imagine other cases where being connected to the Internet is not necessarily a desideratum.

By disconnecting MW0 from Internet, transforming it into a "local area network" (LAN[6]) WiFi hot-spot and by properly configuring and installing all necessary SSL certificates in advance, the Teacher artefact has been put into " locally on-line mode". In such a mode, students physically present within some space (e.g. garden)

[6] In context of a garden, I sometimes speak not about LAN but "garden area network" GAN.

could still connect to the server physically present in the center of the space (e.g. middle of the garden) and communicate with each other in spite of realizing their learning tasks at different places (e.g. different corners of the garden).

Additionally, once the Teacher artefact will get reconnected to the wider Internet - contents of the hitherto separated asynchronous room are automagically synchronized with the rest of the Matrix ecosystem.

Teacher.solar project demonstrated that it is both possible and feasible to have a fully functional on-line learning stack - with audio broadcasting, command-casting, and Matrix-backed asynchronous rooms - which is running on a local device. This is the major technological insight provided by the project.

Initial Matrix room identifier	Homeserver of origin	Number of users
#edu-botanics:m3x.baumhaus.digital	m3x.baumhaus.digital	51
#edu-ODE-teacher.solar:m3x.baumhaus.digital	m3x.baumhaus.digital	50
#art-plants:1.teacher.solar	1.teacher.solar	22
#enigma-voynich:1.teacher.solar	1.teacher.solar	7

Tab. 1: Identifiers, homeserver, and number of users in some asynchronous rooms which emerged during the teacher.solar project. State: 1.11.2023 / AE531101.

Table 1. provides overview of asynchronous Matrix rooms which were created for the purpose of different teacher.solar seminars. Note that the knot 1.teacher.solar is most of the time intentionally disconnected from the global network.

5.3 Software axis

For obvious reasons, solar-powered digital, on-line learning tools must use software whose information-processing and data-transfer bandwidth costs are as low as possible. It has been observed already in March 2021 that existing open-source software tools for on-line learning and communication like Jitsi or BigBlueButton are too complex, computationally demanding and bandwidth-expensive to be executed on a RaspberryPi microcomputer which is powered by a solar power bank. Thus, the teacher.solar scientific assistant Mr. Brodbeck has been charged with the task of creating a much more minimalist a software whereby the video-broadcasting paradigm would be substituted by something we call command-casting [7].

Commandcasting (CC, shortened form of "command-broadcasting") is the distribution and execution of program code snippets and associated data forwarded from the source viewport (e.g. teacher's browser) to one or multiple target viewports (e.g. student browsers). This allows to display presentations folios on student's devices

[7] In the [brodback2022teacher], we use the term “code-casting” and not “command-casting”. There is a subtle difference between the two, but for the purpose of this report, both terms can be considered equivalent

with much less bandwidth than using the classical " screen-sharing " approach. The switch from video-broadcasting to command-casting paradigm finds its manifestation in the teacher.js software suite.

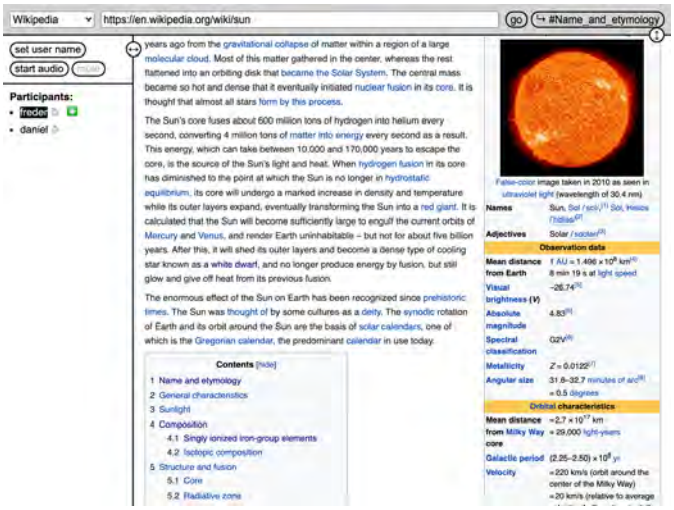

Abb. 5: Screenshot of teacher.js application with Wikipedia module activated. Actions which teacher executes on wikipedia page are replicated to student browsers by means of command-casting.

In teacher.js, events on the teacher's client (e.g. slide changes in a presentation, following a hyperlink in wikipedia article, change from etherpad module to matrix chat module etc.) are transmitted to all other connected participants here, ensuring that they stay in sync. As a result, the students see exactly what the teacher sees. In addition to audio/voice call functionality, the application can be extended for various purposes through the integration of additional modules. Currently, there are modules for text chat, presentations, Wikipedia, and collaborative text editing.

Note that after proper setup of SSL certificates and pre-caching of course-relevant Wikipedia articles on teacher's artefact, teacher.js can run seemlessly in local online mode.

Teacher.js is a web application programmed in nodeJS, uses Svelte library for frontend, Websockets for communication between the sever and the client and Hydrogen.js as a Matrix client which communicates with matrix-synapse server. Audio broadcasting between participants of the seminar is realized by Janus. Wikipedia caching and presentation command-casting are mediated by Kastalia Knowledge

Management System (Kastalia KMS). Functionality of collaborative document-editing by means of Etherpad-lite module is also integrated. C.f. figure 4. for further desciption of the architecture.

Note that after proper setup of SSL certificates and pre-caching of course-relevant Wikipedia articles on teacher's artefact, teacher.js can run seemlessly in local online mode. Id est, students and teachers can share a collective digitally-supported learning experience also on places without internet access (e.g. forest, underground, indoor).

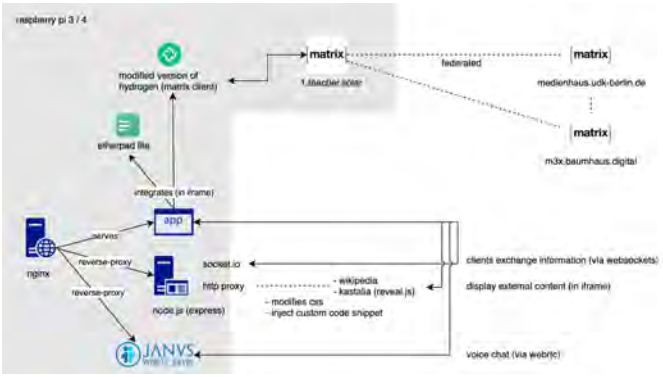

Abb. 6: Architecture of teacher.js software suite. Figure from IEEE publication [BH22].

5.4 Hardware axis

The main challenge of the teacher.solar project consisted in designing, materializing and deploying diverse hardware prototypes, resp. artefacts. In the context of teacher.solar projects, these artefacts were supposed to be solar-powered and, in ideal case, also without batteries. Challenge was even more difficult due to the fact that in order to achieve the idealized state of "full solarity", both teacher server as well as student devices involved in the ODE process were supposed to be solar powered. And to make issue even more complex, the hope was that the "student artefacts" will be built by student themselves. That is, that artefact created for students will ultimately be the artefacts created by students.

5.4.1 Teacher artefacts

The main teacher artefact issued from the project was my Magic Wand 0 (MW0). In its essence, MW0 is a headless - e.g. no screen and no keyboard - Raspber-

Abb. 7: Avocad0 artefact

Abb. 8: MW0 artefact + some additional teacher.solar gear (solar panels & solar backpack, e-ink phone, e-ink tablet & sun glasses with bluetooth audio headphones).

ryPi computer attached and a solar Powerbank (c.f. Figure 5). RaspberryPi has additional components - notably the GSM module and 4-microphone circular LED Respeaker HAT - attached to it. Software-wise, it runs a Raspbian Linux with additional systemd services (teacher.js, matrix-synapse, Janus, Kastalia KMS, nginx, bluesalsa u.s.w.) in order to provide completely autark ODE experience. The whole system is attached to a piece of wood of unknown origin making the whole setup both piece of art and teacher instrument in the same time. Additional Arduino microcontroller with 12 different sensor types is also attached to the wand.

MW0 is more closely described in [Hr].

When it comes to its components, the second teacher artefact known as Avocad0 is very similar to MW0. But contrary to MW0 whereby all hardware is exposed to exterior, Avocad0 has a rounded form consisting of two lasercut pappelholz planes attached to each other with woven polymer tubes. Thus, the teacher's server running in the interior is better protected against unfavorable weather conditions. Indeed, it happened after one teaching session in my garden that I left the server - embedded in Avocad0 shell - hanging on a plum tree growing in the middle of the garden. Both the hardware and the artefact survived without any harm quite heavy rain which followed next night. In short, Avocad0 artefact can be best visualised as an open-source, DIY, locally on-line, edge-computing antithesis to personal assistant systems like Amazon's Alexa.

Ultimately, both MW0 and/or Avocad0 can connnect - by means of bluetooth - to a solar boombox (shortened as Solbox) artefact. In its essence, solbox is a

batteryless bluetooth speaker which uses energy captured by its solar panel to amplify bluetooth audio signal. Signal is transmitted to a DIY cardboard by means of a sound transducer - also known as “shaker” - so that a fairly loud sound is produced.

The main challenge in designing solbox consists in giving it ability to stay operational even if sunlight conditions temporarily worsen - for example due to sun hiding itself behind a cloud, or due to shadow of a person passing by. Due to this reason, implementation of energy-buffering mechanisms is essential. And since batteries often tend to be considered as “‘dirty” by Solarpunk community, trials have been executed to perform energy-buffering by means of so-called “super-capacitors”.

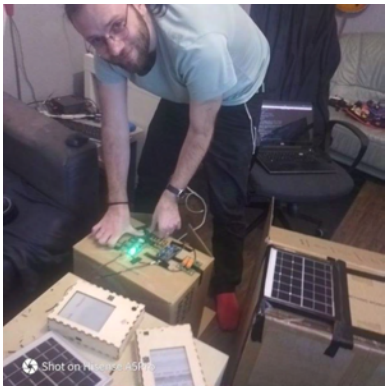

Abb. 9: Master engineer with Solbox 0 and Solbox 1.

In case of Solbox 0 - which is, after 2 years since its conception still fully operational and often plays some nice tunes when the sine is shining - the components used were off-the-shelf audio microcontroller combined with a professional supercapacitor evaluation board. Our aim was to go one step further, though, and thus, the chief electronic engineer of the project spend significant amount of time in design of our own integrated circuit which would allow one to transform a:

- Arduino Nano Connect RP2040
- couple of super-capacitors
- solar panel
- sound transducer
- cardboard box

into a lightweight but loud, solar-powered, batteryless bluetooth audio speaker.

For few days, even the prototype 1 worked. Then, a small booster chip burned somewhere due to reason yet to be discovered - light too strong, booster chip positioned on a wrong place, you name it [8] - and that's where we are now.

Still, all other prototypes - i.e. MW0, Avocad0 and Solbox 0 - are fully operational even two years after their conception. On their SD card, MW0 and Avocad0 contain two out of three clones of 1.teacher.solar system, including the archive of all course-relevant Wiki articles, Kastalia folios and associated matrix rooms.

5.4.2 Artefacts for students

In order to be able to communicate with the teacher's server, one also needs devices - or consoles - by means of which students resp. teacher, communicate. Non-negligible amount of effort was invested into creation of such devices practically from scratch, i.e. from publicly available off-the-shelf components. Thus, the supercapacitor-buffered docking circuit for Arduino Nano Connect RP2040 was intended to be extended with an E-Ink display and programmed in a manner that the change executed by teacher would be automatically propagated on the display. Unfortunately, for reason explained in footnote 5, technical issues emerged during design of the PCB which turned out to be unsolvable within limited scope of the project.

It is worth noticing, however, that experiments performed during SoSe 2022 seminar "Design and deployment of outdoor digital education artefacts" have proven that in case of good solar conditions, one does not need neither the battery nor supercapacitor buffers. Thus, an Arduino Nano Connect RP2040 connected solely to a Solar Panel and a 7-color WaveShare e-ink display was able to:

- connect to WiFi network provided by the teacher artefact
- download the image of active folio whenever teacher moved in his presentation
- display it on an e-ink display

This minimalist setup, however did not provide any audio functionalities.

Thus, to fully exploit all features which teacher.js software can offer, students mostly used either their own smartphones or six colored e-ink Onyx Boox tablets [9] for

[8] Explanation of the PCB failure according to its engineer: ''Most likely culprit seems to be improper layout - sometimes its not sufficient for all the components to be connected correctly, but also the topology has to be correct to avoid bottle necks in current flow - this is doubly important with power regulation circuits. It's possible there's some discrepancy between our implementation and the manufacturer's recommendations."

[9] Generously borrowed by InKueLe project.

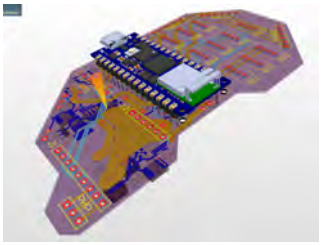

Abb. 10: Sketch of the design PCB with embedded Arduino Nano Connect RP2040.

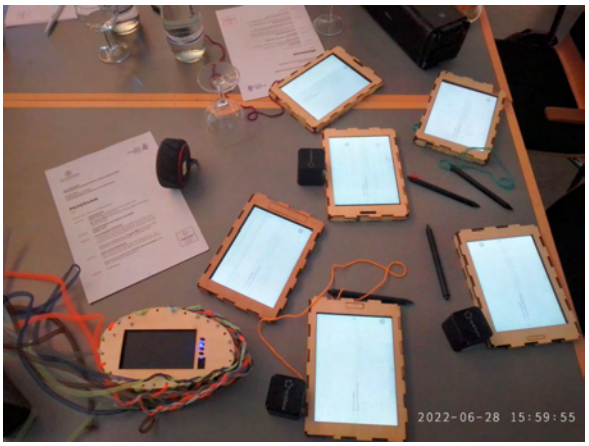

Abb. 11: Avocad0 teacher server and six associated learner e-ink tablets protected in specially laser cut wooden enclosures.

which students assistants laser-cutted nice wooden protective enclosures which better fit the "Solarpunk" aesthetics of the teacher.solar project.

5.4.3 Artefacts by students

The ultimate objective of the project was to increase student competence in design of solar-powered ODE artefacts to such a level that they would be able to create their own ones. In cases of certain people involved in the project - notably Mr. Kapanadze, Mr. Brodbeck, Mr. Kim & Ms. Hsu (all former students) - it can be, indeed, argued that fundaments for such competence have been successfully established and the ultimate objective has been, at least in part, attained. However, as illustrated by Figure 12, even students with lesser technical skills yieled mentionworthy results.

6 Lessons learned

For its limited 25.000 eur budget, teacher.solar was a very ambitious project. There is a long way from solar energy to a self-catalysing didactic concept, and we tried to cover it all. On the technical side, solar panels were positioned, circuits designed and printed, hundreds small components placed & soldered, software - both for teachers as well as well for students - was developed, new means of communincation (Matrix) have been tested. On didactic side, students were brought to gardens and parks and

Abb. 12: Student-made "Fountain" and "Hat" artefacts.

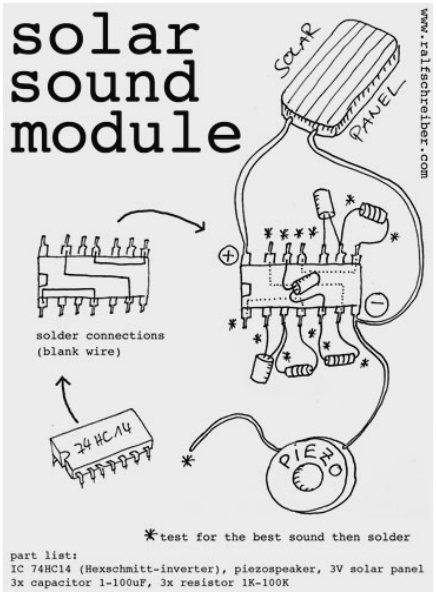

Abb. 13: Description of sound-generating solar module based on Hexschmitt-inverter.

asked to use systems which they never used before to acquire competences which were - to some of them - completely new. Thus, it is no surprise that some things worked, and some didn't.

7 What didn't work

When it comes to hardware development aspect of the project, we failed to obtain a robust circuit design which would allow us to substitute batteries for super-capacitors in an extent that ODE sessions could be reliable performed on devices embedded in such circuits. But this is of little surprise: even corporations with five-orders of magnitude higher budgets apparently did not fully solve the problem neither and devices like solar-powered, batteryless smartphones still wait for their time of inception. Storing energy is tricky.

When it comes to teaching/didactic aspect of the project, I advise future readers of this text to take note of following advices:

1. ODE seminars should be as less infrastructure-reliant as possible
2. use digital tools only there when there's good reason to do so

3. competence transfer is successful only there, where teacher's competence of the field is solid

The first advice may sound obvious: if special indoor equipment (e.g. soldering lots, microscopes, gene sequencing u.s.w.) is necessary to perform seminar-related tasks, these tasks cannot and will not be accomplished within the context of an outdoor course. True, in creative context of an art university, one is free to curricular experiments, explore diverse "hybrid modes" and some innovations - e.g. "solar soldering" may potentially be even born out of it. But in a more classical context too much experimentation can be detrimental to the knowledge & competence transfer process.

Concerning the second advice: in our reform-obsessed, actionist times, one often has a tendency to replace old and cheap analogue methods which demonstrably work with novel, digital, expensive methods and tools which promise to work. For example, in collaborative plant drawing exercise (c.f. Figure 2), there were both groups using both classical pencil & paper as well as groups composed of students using their e-ink tablets and synchronized by a colaborative drawing app. While results of both groups were beautiful, it seemed to me that the analogue group sharing the same large format paper canvas enjoyed the process more than the group where each student worked on a separated canvas, albeit digitally synced.

Concerning the last advice: in the teacher.solar project, the transfer of ability of building & deploying solar-powered ODE artefacts has been defined as the "ultimate goal". What sounded like an interesting, self-catalysing idea - i.e. teaching students how to build the very instruments involved in the teaching process - clearly attained its limits due to the fact that it was originally not even clear to me (e.g. teacher), how such instruments should look like. Now, the clarity is there: but in 2021, when the transfer was supposed to take place, it still wasn't.

8 What worked and works

Here is a little summary of what I consider to be "positive outputs" delivered by the teacher.solar project:

1. outdoor courses are healthy, refreshing and students love them
2. it is possible to enrich outdoor experience with digital components, notably be replacing light-emitting (LED, OLED) with light-reflecting (E-ink) screens
3. Internet access is not a conditio sine qua non of a successful ODE session: portable teacher servers are possible and demonstrably work

4. Matrix protocol allows both locally on-line as well globally on-line modi as well as transition amongh the two
5. with a properly chosen 1 Watt solar panel, microcontroller and an e-ink screen, one does not need neither batteries nor supercapacitors to show on student's console the content which teacher wants him/her to see
6. enriching the ODE session with AI assistents (e.g. Merlin app for bird song recognition; NaturBlick for plant identification) gives teacher completely new abilities

Elaborating on the sixth point, crossover of the teacher.solar project and the "Bildung Biodigitale" seminar series concept led me to proposal of a so-called "eco-artificial education". That is:

''Ecoartificial education (EAE) integrates those forms of pedagogical and didactic practice where artificially intelligent systems are being deployed for the purpose of increase of Hs knowledge and respect of the surrounding biosphere."

9 Dissemination

The main publication issued from the project is "teacher.js: A low-bandwidth Digital Tool for Outdoor Online Teaching" [BH22]. The MW0 artefact is more closely described in article "Three Principles, 2 Sub-principles and One Magic Wand for Harm Minimization and Prevention of Technological Addiction in Human Children" [Hr]. A pre-print "Short Plaidoyer for Introduction of EcoArtificial Education in Diverse Curricular Systems of the Planet Earth" is also of relevance given that teacher.solar is direct precursor of the notion of "eco-artificial education" [HH].

In 2021 and 2022, the project teacher.solar and associated sub-projects, practices and concepts have been presented at multiple public events, Table 2 provides their overview. Aside these, the project has been presented in context of other smaller or internal events (UdK's AG Online Lehre, ECDF Brownbag meeting, semester introductions for study program Art & Media and Visual Communication etc.).

Other resources which emerged during the project and which are hereby transfered to the public domain:

- teacher.js code is available at https://github.com/freder/teacher.js
- code for eink solar display based on Arduino Nano Connect RP2020 is available at https://github.com/hromi/OutdoorEducationArtefact
- schemas and PCB designs for supercapacitor-driven microcontroller board are available at https://github.com/nikolozka/teacher.solar

When	Event
February 2021	teacher.solar lightning talk at digital meeting of Stifterverband 2020 fellows (online)
May 2021	first presentation of teacher.js prototype at Berlin Open Lab Symposium (online)
November 2021	teacher.js presented at University:Future Festival (online)
March 2022	Demo of teacher.js at Fellow meeting (Essen)
March 2022	Presentation of teacher.js software at Eurasian Conference on Educational Innovation (ECEI)
May 2022	gardens.digital installation at BOL/ECDF event Transforming Communities (Berlin)
July 2022	Stifterverband Senior fellows use teacher.js running on Avocad0 artefact to do their first recording of Ode an die Didaktik (Berlin)
July 2022	Lightning Talk about Digitally Assisted Outdoor Teaching Presented at Stiftverband's Lehrkonferenz (Berlin)
September 2022	Bildung biodigitale and artefacts issued from the teacher.solar project presented at Bits & Bäume conference (Berlin)

Tab. 2: Presentations, talks, demos.

10 Tenure

Support of the Berlin University of the Arts during the conception of the project proposal has been exemplar, as well as support with all accounting-related issues. Content-wise, however, after the project was initiated, it didn't seem to raise much interest [10]. Thus, after multiple initial tentatives intending to communicate the message "look what we do, it is important" to other University & Einstein Center Digital Future (ECDF) & other so-called "innovation hubs" colleagues, and after not receiving any feedback whatsoever, I decided not to waste time with trying to convince anyone of anything. With one exception: within the ECDF context, the description of the "teacher.solar" and "Bildung Biodigitale" concepts have been an integral part of the portfolio [Da21] with which I applied for tenure within the context of ECDF's "Bestenauslese".

Except the information that my application was refused, and except a non-written statement that my research and my pedagogical practice are "of little value" coming from the person who selected to Bestenauslese committee, I never obtained a single bit of feedback concerning the reasons why it was rejected.

Thus, in times where investments for "digital learning" and "sustainability" abound both in public as well as in private sector, no additional funding has been obtained for a project which introduces at least five fundamental innovations at the very

[10] Bright exceptions to this statement being prof. Reese and some colleagues from InKüle project.

interesection of these two fields. But that was expected: a teacher is neither a businessman nor a lobbyist*e...but simply a teacher [11].

11 Stifterverband Fellowship in High School Education

Being selected in a fair-play process and thus becoming one of few applicants of non-German origin who have been attributed the Fellowship was a big honor. In Essen, first contact was established; in Berlin, it was strenghtened by verse & song [12]; in Freiburg, "kollegiale Beratung" helped me to do good decisions.

In particular, I can imagine future collaboration in domain of "outdoor digital education" with prof. Dr. Jutta Papenbrok (Institut für Botanik, Uni Hannover); prof. Dr. Lina Oravec (Institut für Musikwissenschaft und Musikpädagogik, Uni Koblenz - Landau); Dr. Franz-Josef Schmitt (Wissenschaftlicher Leiter des Praktikums Master Physik bei Martin-Luther-Universität Halle-Wittenberg) and Mr. Traugott Haas (Design, Uni Vechta).

Additionally, I am still more than willing and ready to facilitate the communication between Fellows by bringing into existence the Matrix homeserver which could significantly facilitate communication within the community and beyond.

[11] Concerning the eternal validity of Schopenhauer's remark concerning the arrow, the G and the target, it is no surprise that no tenure or institituionalization of the teacher.solar happened or is bound to happen. For tenured can only be such ideas, things and target whose immediate utility is evident even to the mass public of the present, and not those which will be seen as such in the future lying well beyond fear&profit-driven imagination of the great many.

[12] All audiotext recordings of "Ode to didactics" are safely archived on 1.teacher.solar node.

12 Danksagung

From UdK, I would like to thanks UdK Master-archivist Dr. Dietmar Schenk for introduction of the Bildung Biodigitale group to Plant-related contents of UdK's archive; prof. Kirsten Reese for being the one without whose support the whole project could have well come to an embarassing end before it even started; Nik Kapanadze for being the most exemplar electro-engineer I ever met and Fred Brodbeck for being the best coder; Hyungjoong Kim for being much more than an assistant; UdK's Präsidium and Administration for both professional as well as human help; to Maria Kyrou and other InKuele people of good will for documenting it all; Tonia Welter BOL for keeping BOL in great shape Jung Hsu for the Avocado lasercut; " UdK Solarpunks " for showing me that it is friendship and not teacher's will to succeed that is the ultimate " Key Performance Indicator " and participants of " Bildung Biodigitale " series for teaching me more about Schweitzerian " Ehrfurcht vor Leben " vis-a-vis all life-forms - including mosquitos and ticks - then I could ever teach them.

The start-up wizzion.com UG also deserves to be mentioned here since it paid, pays and will pay for domains gardens.digital and teacher.solar as long as it will not become insolvent.

From Stifterverband, Frau Jorzik for being the one who brings it all together, Mr. Andreas Weber for a talk atop the highest Berlin skyscraper on a moonlit-evening and all Fellows from Essen 2022, Berlin 2022 and Freiburg 2023 meeting for joining me at the toast ending with words " Slava Ukrajine ".

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