Digital Fabrication and Maker Movement in Education
Making Computer – supported Artefacts from Scratch

Deliverable D2.3

Critical evaluation of innovation management

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2	July	UEF and EDUMOTIVA	Description of pilot practices
3	August	LNU	Evaluating bottom-up initiatives
4	September	UniPD	Internal QA

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EXECUTIVE SUMMARY

The core of this deliverable concerns the innovative practices introduced by the ecraft2Learn project, inspired by exploration and reflection upon innovation management techniques. Innovative technologies as developed in WP4 are only a first step, as we showed in D2.1 where enablers and barriers were described. The scale of innovation is determined by adaptive *innovation behaviour* which recognizes the current limitations of the existing institutional setting and finds ways to be innovative, even though optimal conditions are not given.

This deliverable includes a general overview of tool usage in the eCraft2Learn ecosystem (chapter 6). As shown, 12 out of 14 tools have been used at least once and about 60% of tools have been used in both pilots. Nonetheless, the aim was not to maximize the number of tools used but to offer a broad variety of tools that could easily support a diverse range of pedagogical scenarios.

Together with a description of innovative practices within the eCraft2Learn pilots, two aspects supported are *open designs* and *co-innovations*. These aspects are fine-tuned in chapters 4 and 5 from a bottom up perspective. This is not to say that we should not continue to demand better equipped schools, improved working conditions for teachers or more funds to further educational research which can produce solutions that are most effective and carry the lowest cost for implementation.

1 INTRODUCTION

The objective of this deliverable is to summarise and critically reflect upon innovation management including

- knowledge management;
- sharing and networking among users;
- and managing the openness of educational materials.

First D2.1 conceptualized innovation and highlighted barriers as well as enablers to educational innovations. Different innovation management techniques were described, whereas the need for a more holistic and systemic approach to innovation within educational systems became evident.

D2.2 provided then a glimpse into the future by means of describing future use scenarios Each scenario was structured according to 4 dimensions: technology, governance, resources and skills. Again, the need to systemic changes became apparent. Innovation cannot be limited to the realm of innovative learning methods, but needs to include teacher education (e.g. providing new skills) as well as changes to providing enough resources (e.g. managing workloads) and the governance of schools (e.g. allowing for more local examinations opposed to centrally developed test items).

The core of this deliverable is therefore the need for being innovative about introducing innovations. Because the limited resources within educational sectors are unlikely to disappear soon. This is not to say that we should not continue to demand better equipped schools, improved working conditions for teachers or more funds to further educational research which can produce solutions that are most effective and carry the lowest cost for implementation. However, until we have these conditions we need to pursue strategies based on open innovation principles and co-innovation, also drawing upon resources outside the educational technology community.

The deliverable is structured as follows:

- Chapter 3 restates the need for open designs and co-innovation.
- Chapter 4 presents innovation management tools helping tapping into the knowledge of external communities (our 'inspiratorium search') and sharing experiences with other teachers as a feature on the eCraft UUI.
- Chapter 5 looks into collaboration and knowledge reuse within craft-related communities such as instructables.com and thingiverse.com.
- Chapter 6 takes up co-design again and reports some qualitative experiences with the UUI as a whole and the materialization of learning processes (sketches, lists, project ideas, code etc).
- Chapter 7 offers a final reflection on eCraft2Learn's innovation theme 'whitening black boxes' and compares it with similar projects using other core technologies (Micro:Bits, Calliope or DIY microcontrollers).

Figure 1 illustrates the two main areas, aiming to support innovative schools: effective access to support materials via different tools and tapping into existing support communities.

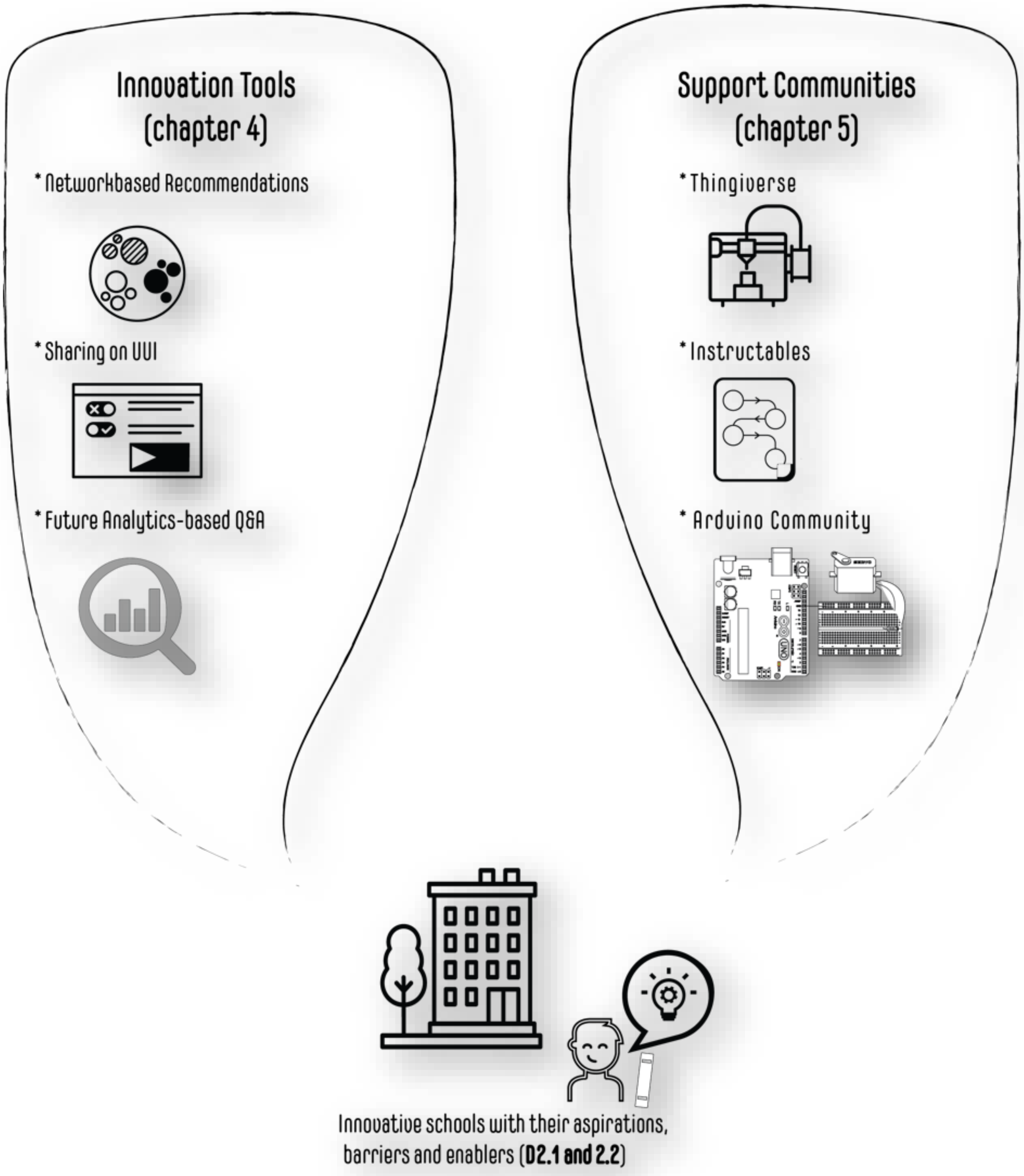

Figure 1:Innovation tools and external communities to support bottom-up innovations

Referencing longstanding sources of knowledge, this deliverable makes an important contribution to the sustainability of project results, when the pedagogical model and core technologies developed in eCraft2Learn need to continue, possibly with reduced input of our project partners to the pilot venues. Innovation is also about continuously observing and improving the status quo. Hence, studying existing communities and their practices highlights possible improvements of the pedagogical model (WP3) as well as finetuning features within the UUI (WP4). And of course, such changes continue influencing WP5 (Pilot management), as experiences from past implementations are used in future trainings and offerings.

2 The need for open Designs and Co-Innovation

Innovative technologies as developed in WP4 are only a first step, as we could show in D2.1 where enablers and barriers were described. The scale of innovation is determined by adaptive *innovation behaviour* which recognizes the current limitations of the existing institutional setting and finds ways to be innovative, even though optimal conditions are not given.

One reason for sub-optimal conditions is often the quasi-market characteristics of educational systems, where the way budgets can be spent is highly regulated and larger initiatives require ministry approval (Voigt, Schön, & Hofer, 2018). Yet, just as in industrial sectors, economic tensions (e.g. salary increases, partly shrinking budgets for labour, higher costs for advanced learning technologies) need to be managed carefully. Today, a carefully developed profile can make a difference when schools need to be merged due to changing numbers of students.

Despite the differences in regulatory structures, the reasons for limited innovation capacities in school and SMEs (small and medium enterprises) are similar: lacking risk capital, less focus on strategic development and shortage of management skills to sustain innovations in schools (Pechlaner & Doepfer, 2013). Hence, it is worth looking at innovation behaviour in SMEs. In Germany, for example, 9.8 % of SMEs invested in research and development and about 35% of SMEs introduced product or process innovations in 2016.[1]

Innovating SMEs represent roughly above a third, which, given the paramount importance of innovations in today's knowledge economy, underlines the need for flexible and innovative ways of innovating, e.g. using *open designs* and *co-innovations*. These two aspects that have already been introduced in D2.1 and are now fine-tuned from a bottom up perspective.

What are open designs?

Open designs are mainly a question of how to go about the process of designing. It is as much about a mindset to be open to external influences as it is about understanding design as an 'open' state of affairs, to be adapted under new circumstances.

Although design and innovation have many aspects in common, such as leading to the creation of novel products and processes, they should be distinguished. Despite innovation research as well as research on design include adoption processes and the cost of innovation, design research operates more frequently with concepts such as path dependencies, semantics and aesthetics (Cruickshank, 2010). A functional innovation can be based upon varying design, with more or less limiting consequences. A simple example is the use of standardized connectors or screws. An innovation that requires adopters to invest in new infrastructures, be it adapters or tools, bears costs that might outweigh the gains of the innovation. Similar differences in focus apply to semantics and aesthetics, when an innovation is judged on a

[1] http://ftp.zew.de/pub/zew-docs/mip/17/mip_2017.pdf

'does it work' premise alone: especially in an application context where technical innovation need to be communicated to a primarily non-technical audience, semantics and aesthetics gain in importance.

The decision to release open designs does not come without implications. 'Open designs' release control and business opportunities can not be based on hijacking customers' future choices, as it is often the practice of proprietary designs. Open design also means, that design is not a practice limited to a professional group of designers, acting as gatekeepers for creation and production processes (Cruickshank, 2016). Open designs lead to collaborative designs, as highlighted in "democratizing innovation" (Von Hippel, 2005).

Open designs are promoted on platforms such as instructables.com or thingiverse.com, where open licenses are a pre-condition for uploading and sharing materials. There we ask the question whether openness leads indeed to collaborative innovation, i.e. are open designs merely consumed, such as printing a keychain without any changing the original design, or are open designs integrated into new ideas and products.

The specific value of open designs is illustrated in **chapter 4.** Open designs can either inspire or be taken as is and further developed. Additionally chapter 4 presents an outline how open designs can be discussed within the eCraft2Learn ecosystem.

What do we mean by co-innovation?

Co-innovation refers to collaborative processes without specifying the stakeholders involved and their specific roles in the process (as it is done in user-centered or user-driven innovation, see D2.1). This provides a more flexible approach to innovation distributed across multiple schools or even collaborative innovation across teachers and knowledgeable experts outside the educational field. This is also how entrepreneurial networks are built. Rarely it is the case that a single start-up covers all aspects of a successful project launch in an optimal way, hence specialized knowledge is acknowledged as much needed, complementary external resource.

Some innovative schools, therefore, have strategic alliances with companies such as Arduino, leading to the "Creative Technologies in the Classroom 101"[2] package, or Ultimaker, with its 'CreateEducation Community'[3].

Taking a cross-community perspective on co-innovation, **chapter 5** presents more in depth analyses of collaboration and innovation behaviors within the communities of instructables.com and thingiverse.com.

3 Innovation Support Tools

The aim of this chapter is to open up existing resources by testing the possibilities of using content from platforms such as instructables.com. More concretely, two questions will be addressed:

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[2] https://www.arduino.cc/en/Main/Education
[3] https://www.createeducation.com/

a) Given that emerging or relatively small communities might not yet have a sizable stock of resources related to technology enhanced learning topics, is it possible to use *knowledge from more established communities* as a starting point, such as instructables.com?
b) Content on established maker platforms goes into the hundred thousand and more. Therefore, when using content from established maker platforms, can we establish *a transparent and effective way to select content that fits users' needs and results in resources being perceived as useful* to learners and teachers?

Hence, the Inspiratorium described in the next section is a tool that enables quick and effective access to materials, teachers can use in preparation of their classes and workshops. However, as discussion at the end of chapter 4 will show, the Inspiratorium cannot deliver pedagogically edited materials and therefore we see its primary function in providing ideas and inspirations about how novel technologies can be used in the context of specific subjects matters.

3.1. THE INSPIRATORIUM: A TAG-BASED RECOMMENDER PROTOTYPE

Looking back in history, every society over the different centuries had its specific demands in terms of skills requirements at the workplace and as a result in terms of education. Thus, broader societal developments tend to influence pedagogy, in terms of teaching methods as well as in terms of educational goals associated with specific skills and competences, required to enter the workforce (Ezewu, 1983). With ever more fluid demands on educational systems comes the challenge of adapting curricula, educational technologies and resources (Elizabeth Unterfrauner, Voigt, & Schön, 2018).

Instructables.com is a platform enabling users to upload and share their do-it-yourself projects, which are commented upon and rated by other users for their quality. The website was launched in August 2005 and obtained by Autodesk in 2011. Figure 2 shows a relatively moderate start during the first 5 years, but since then monthly uploads have been overall on the rise. Instructables.com promotes a specific format for writing *instructables* – e.g. project descriptions -, including a step-by-step description and images for in-between results. Data on authors and their projects can be accessed via an Application Programming Interface (API). By October 2017, users had published roughly 250.000 projects, from which we obtained a dataset of 225.681 projects, published and shared by 74.824 distinct first-authors.

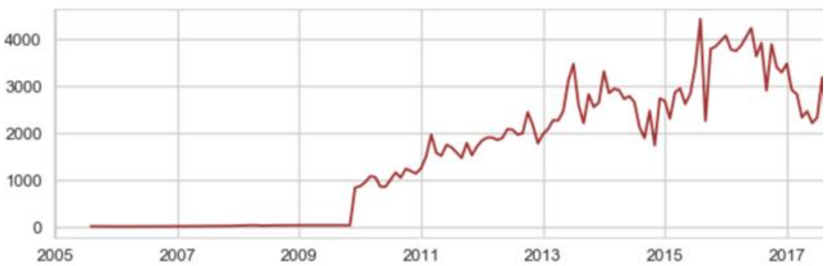

Figure 2: Project uploads per month

If we look at the distribution of published projects per platform user we see a long-tail distribution, fitting best a log-normal distribution (Figure 3). Figure 3 shows two density functions, with the continuous line indicating the actual distribution of projects per user and the dotted line shows a lognormal distribution. On the x-axis we see the number of projects and on the y-axis the probability distribution. The long-tailed distribution has been tested as described in (Broido & Clauset, 2018) using the power law python package (Alstott, Bullmore, & Plenz, 2014). A practical interpretation of a long-tailed distributions is to see it as an indicator for a slow or maybe not too intuitive start, representing the large majority of users having just one project published. Figure 3 shows that only a few active users, namely the top 20 users by the time of analysis, had more than 200 projects. The most prolific user had about 500 projects, mostly in the crafts, gardening and food categories. However, projects tend to be mixed and in another case of a user with 179 projects, we can see a variety of themes including minimalist LED clocks, photography and chickpea meals. Furthermore, screening the top 20 users, it seemed that they had professional incentives to produce instructables, either as teachers, small businesses, makers or managers of makerspaces.

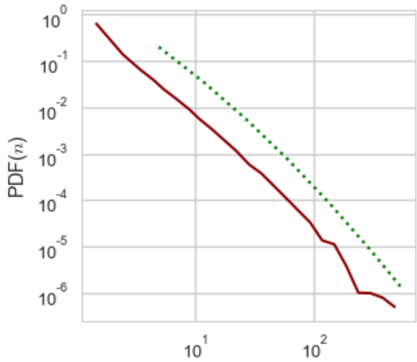

Figure 3: Probability distribution of projects per single author

Early on we discarded the idea of selecting author based on their project profiles, this would go against our intention to identify technology projects embedded in other areas such as gardening or art. We also looked into the self-descriptions of users in order to see whether there was a discernible education community. Without claiming that such an approach could not be promising, a first frequency count of keywords generated rather low numbers: student (1226), maker (961), school (790), teacher (299), company (255), fab (253), education (185) and ‘instructor’ appeared 66 times.

Lastly, platform activities can be described in terms of ongoing collaborations, i.e. visible by the connectedness of an author. Connectedness refers to the number of people, an author has collaborated with. The rationale behind this measurement is that authors who contributed to more projects are more experienced and that project descriptions that were generated in collaboration with others, most likely have had an internal peer review process increasing the quality of the descriptions.

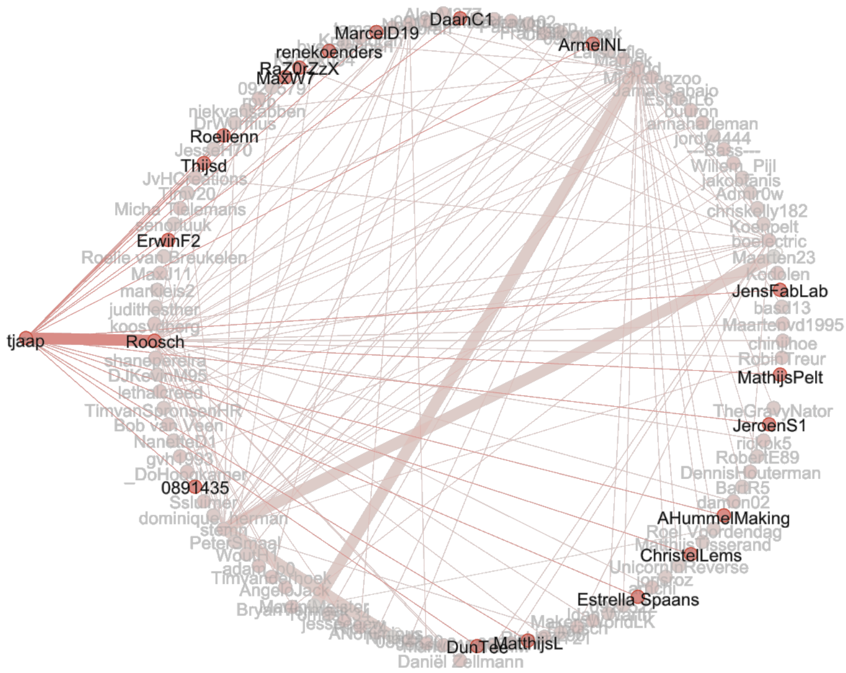

Figure 4: Number of collaborations with other users

Figure 4 shows the largest component of the instructables network with 116 authors collaborating with, on average, 2.15 other authors. For example, the highlighted author ‘tjaap’ in figure 4, collaborated with 19 other authors and produced multiple project descriptions in collaboration with user ‘Roosch’.

3.1.1. Content: Types, Categories, Channels and Tags

Instructable.com content can be separated into two types: projects (97%) and guides (3%). Guides contain themed collections of projects around topics such as micro-boards or magnetism. Each project is allocated to one out of eight categories, with technology, craft and workshop being the most popular categories (see Figure 5, left). Originally content focused mostly on projects such as building electronic or mechanical devices to solve common problems around the home. The scope of the project has then expanded to include less technical categories, including Food, Living, Outside or Play.

Over time, the category ‘play’ was used less and, as expected, the category ‘costumes’ shows seasonal dependencies. At a more detailed level projects are organized into channels and can be described with key-words. Arduino is both the most frequently used channel (see Figure 5, right) and the most frequently issued keyword, which again highlights the community’s technical affinity.

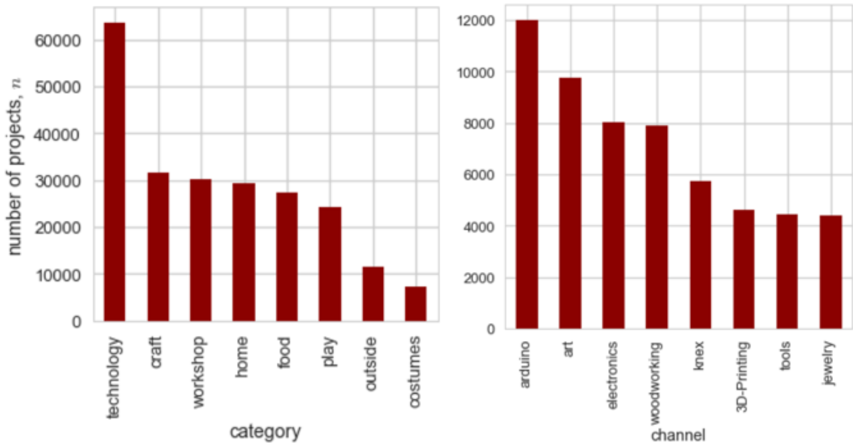

Figure 5: Number of projects for the top eight categories and channels

So far, we analysed options to filter content on instructables.com by categories and channels, which is a useful first step to narrow it down but does not leave many additional options for finding projects beyond pre-established categories. For the next step we generated a network graph based on user-allocated tags (Figure 6).

The size of each node reflects the frequency of the 'tag' and if two tags are connected then this means that at least on project uses both tags. This way, for example, it will be possible to find projects that use the tags 'solar', 'lego' and 'iPhone'- tags that could be relevant in a school context – leading to a project that describes building a USB charger in a casing made by Lego bricks.

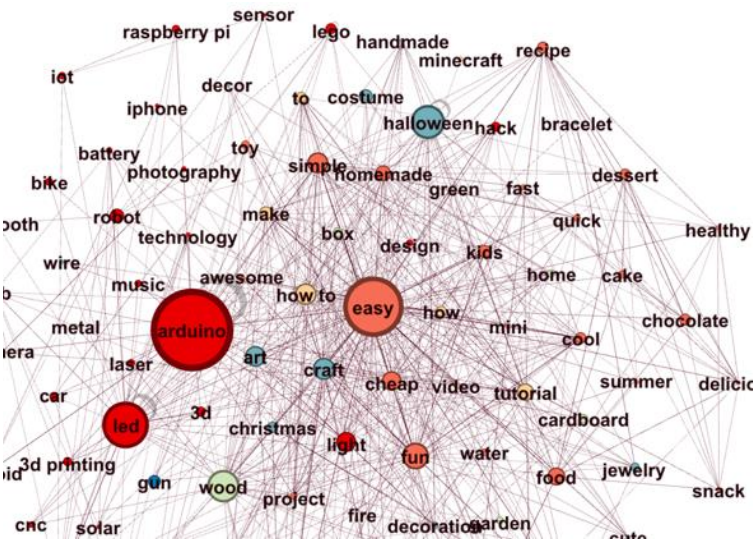

Figure 6: Tag-based content net

Another characteristic of project descriptions is 'step count', i.e. the number of steps used to describe the process of producing a specific outcome. Figure 7 shows a histogram of steps per project.

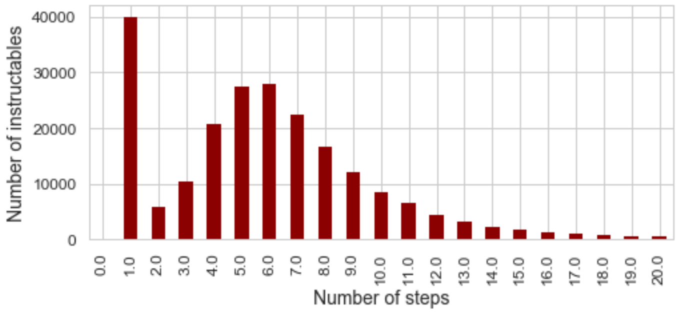

Figure 7: Number of steps per project

An interesting question would be whether 'step count' is positively related with pedagogical quality. 18% of all projects have only a single step, otherwise most project use 5 or 6 steps to break down instructions within project descriptions.

3.1.2. A Tag-based Recommender Prototype

Providing the tag-based content network to end-users is close to providing a first prototype of a recommender systems as discussed in (Manouselis, Drachsler, Vuorikari, Hummel, & Koper, 2011). Manouselis at al. distinguish different recommendation goals, including recommending 'content related to a learner's current interest' and 'content related to specific topics', both scenarios can be covered with a tag-based content network as described in the previous section.

The user interface of the prototype is shown in Figure 8. Users can select tags either from a list or by directly clicking on a node. As shown at the bottom of figure 8, a list of projects, ranked by likes, is generated, depending on the tags selected. All dots are color-coded: orange means that a tag is already selected, grey means that there is no project using the already selected tags and yellow means that there are projects using this specific combination of tags.

Figure 8: User interface of tag-based recommender prototype

An architecture sketch of the system behind the user interface is given in Figure 9. However, we are aware that more complex recommendations such as recommending a preferred pathway through a list of resources would require observing users' interactions with the system and modelling users prior knowledge about a given topic.

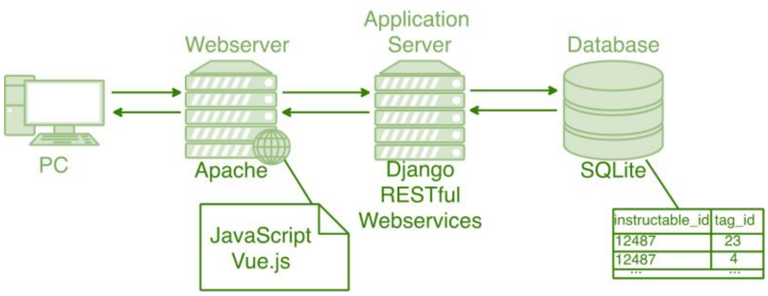

Figure 9: Architecture sketch of tag-based recommender prototype

At the moment our prototype can filter resources by topics but does not take into account yet the importance of selecting materials with an adequate level of complexity so that users are neither over- nor underchallenged (Hedegaard, 1992).

3.1.3. First Evaluation Results

The first objectives to be achieved with the prototype were related to makers' or teachers' needs to find resources which addressed the functioning of specific technical components (e.g. LED, DC motor, micro-boards) or tools for designing and programming (e.g. tinkercad.com or create.arduino.cc) in an applied context (water, garden, green, reuse etc.). At this point, it is important to be aware that the tags are attached to concrete objects and projects, hence more abstract tags such as 'sustainability', 'geography' or 'equity' are less frequently used.

Based on Manouselis et al.'s (Manouselis et al., 2011) overview of recommender systems in technologically enhanced learning settings, we established the following evaluation criteria:

- Degree to which a recommended source uncovered hidden aspects of a topic.
- Degree to which a recommended source included technical as well as pedagogically useful ideas and explanations.
- Likelihood that the recommended source would actually be used
- Likelihood that the recommended source would need considerable reworking before it could be used.

In order to support the data collection for these evaluation criteria, a workshop with 12 teachers and tutors was organized. During that workshop we discussed the need for diverse types of resources helping teachers not only with the technical aspects of digital fabrication technologies in classrooms but also with the logistical or pedagogical implications of using specific technologies with students. Part of the workshop was an exercise where participants were asked to imagine their preparation activities for a class involving digital fabrication and choose between two and three tags that would adequately describe their needs for resources. They were then asked to visit the first two projects recommended and rate them according to the statements provided in figure 10. Number one to five on the provided Likert scale equal 'very much disagree', 'disagree', 'neutral', 'agree' and 'very much agree'. In two cases, the selected tags produced a list with a single resource only, hence we got feedback for 22 recommended projects.

Figure 10: Average score of recommended resources (n=22 projects, rated by 12 teachers)

As shown in Figure 10, overall the recommended resources were perceived as useful enough to be integrated in a classroom. The possibility to extract pedagogical knowledge from projects on instructable.com was rated the least favourable, with a majority of respondents disagreeing with the statement 'The resource included helpful pedagogical knowledge'. However, that was to be expected since users of instructables.com see themselves first and foremost as technical experts or tinkerers and less as educators. Nonetheless, the pedagogical value of step-wise explanations, including the necessary details to also replicate a project step is a frequent topic in comments. With 50% of the resources, workshop participants agreed with 'I discovered opportunities I was not aware of before.' We also see this as one of the main benefits of looking into existing project descriptions, the chances that a project matches a specific user problem are rather small but providing inspiration to a teacher in search for a meaningful example or application area is a reasonable expectation. One common question was whether querying the tag-based network and searching through instructable.com's search engine would provide the same results. Indeed, finding resources is the main business of search engines. However, preliminary tests indicate that whereas instructable.com works fine for frequently used combinations such as 'arduino' and 'water', leading to similar results of automatic plant watering systems, less frequently used combinations such as 'arduino' and 'jewellery' are better served by relying on 'tags' provided by users.

3.1.4. Discussion

At this stage it is still early for a final verdict on the overall value of hacking community knowledge to empower educational communities on their path to more hands-on learning, including digital fabrication tools. The current evaluation happened in a workshop, however, the final recommendation tool is planned to be integrated into a larger support system together with links to open educational resources, tool recommendations for learners and the possibility to support learning analytics running in the background. In such a context feedback can be given online and larger numbers of users are addressable.

Revisiting the research questions posed at the beginning of chapter 4, we would conclude that tapping into resources generated by relevant communities such as instructables.com is a valuable endeavour. The inspiration these resources can provide for teachers and learners as well as the technical details included in project descriptions was mentioned positively during the evaluation workshop described in the previous section.

Concerning the second question about a transparent and effective way to filter external resources for their use in an educational context, we would say that there are some promising options, but most likely direct feedback given by users integrating resources into their teaching and learning practices is needed to produce more accurate recommendations. For the moment, the list of recommended resources is ranked by likes. However, in the future we can also provide the option to rank recourses by the connectedness of their authors or the number of steps featured in a project or a combination of multiple measurements.

To conclude, repurposing the effort from the instructable.com community to benefit education is an effective way to avoid reinventing the wheel. What is left to do, however, is opening up platforms and proactively supporting the reuse of materials (Voigt, 2018). This is not limited to choosing creative commons licenses, which is already encouraged, but also includes supporting rich APIs and giving sufficient visibility to the information contained within project descriptions (e.g. project collaborations and descriptive tags are currently not visible on published instructables).

Last but not least, education and technology are not necessarily an easy match (Collins & Halverson, 2018). Teachers, who are traditionally seen as domain experts need to embrace a diversity of knowledge sources, skills acquisition and learning by doing are equally valid approaches and education systems need to encourage individuals to take on more responsibility for their own learning. These are changes that happen outside technical systems, however they are critical conditions for technical innovations to unfold as envisioned.

3.2. SHARING AND DISCUSSING PROJECT-IDEAS, OFF- AND ONLINE

The previous section has shown how an external community such as Instructables.com can provide inspirational ideas and design content. This section is to argue for the importance of supporting sharing between and discussion among users of eCraft2Learn technologies. Since all members of eCraft2Learn pilots share the same core technology and open resources, we can assume that if something doesn't work or works particularly well, then this might be the case for multiple users. Also some project settings will foster the use of a particular tool while others setting might make it superfluous. An example for that (as also discussed in section 6.1) might be a team's use of a 'to do list', which adds more value to project work if the project is executed over a number of weeks rather than over a number of consecutive days, when students are likely to remember tasks from one day to the next.

Overall, we distinguish between sharing among students (Figure 12) and sharing between teachers (Figure 11). Figure 11 shows a first implementation of uploading and commenting upon educational materials.

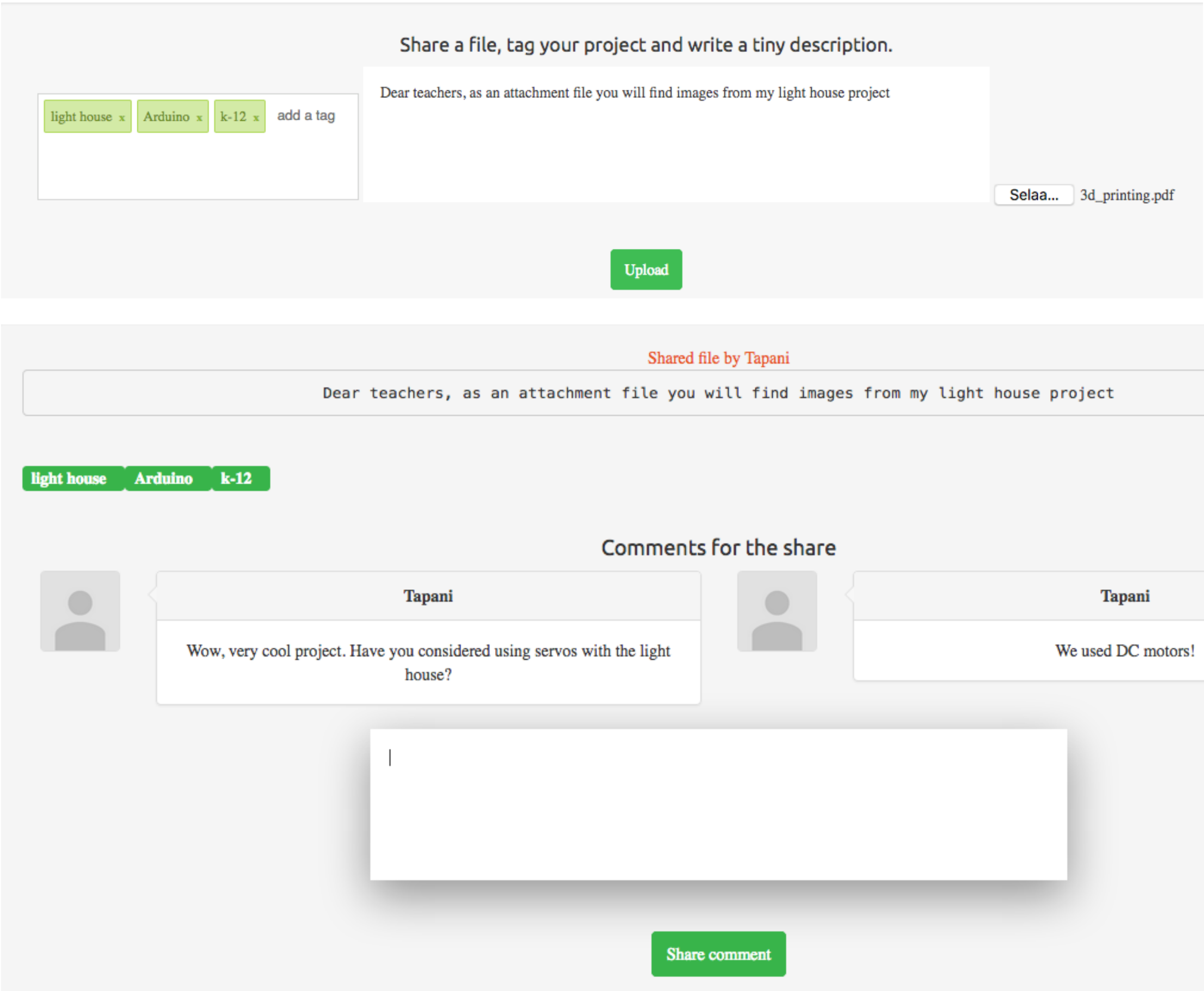

Figure 11: Sharing and commenting between eCraft2Learn members

After logging in, teachers can upload and comment their materials. Further development might include references to the tools used as well as the possibility to stop sharing materials.

For time being, sharing materials is still under development and concrete use scenarios need to be agreed with the pilots.

An additional way to ignite discussion can come straight from work shared by students, who have a list of 'personal' and 'public' work items (Figure 12). Unlike the 'sharing among teachers', which resides on the learning analytics page, 'sharing among students' is accessible through the UUI.

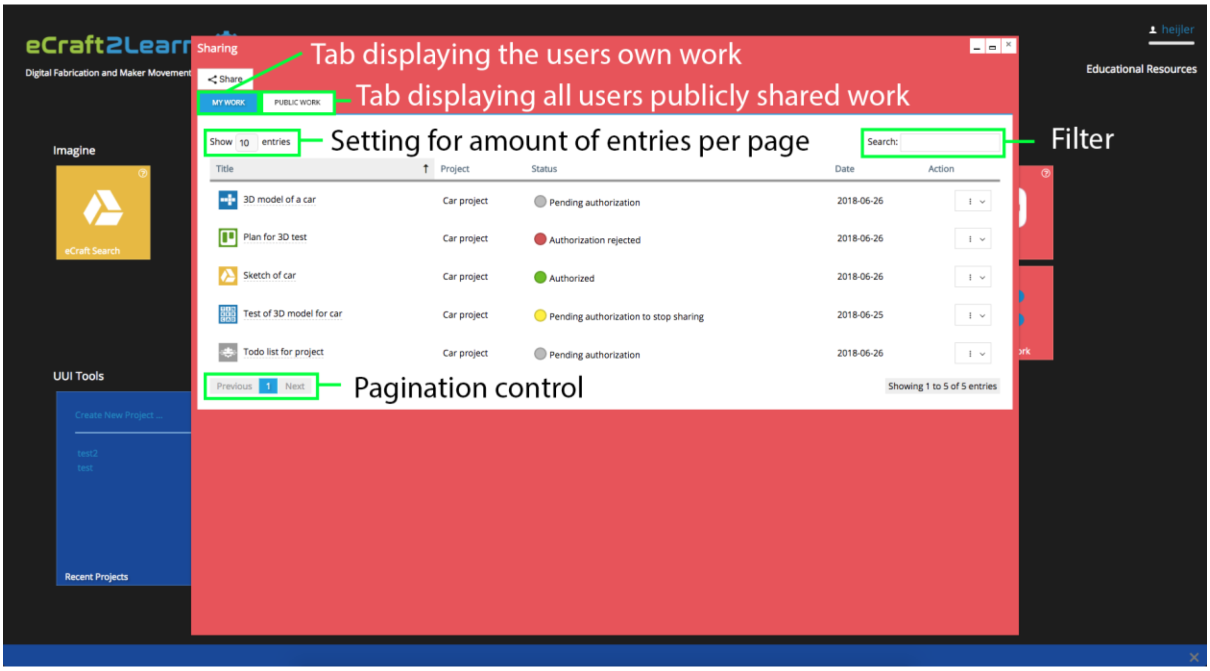

Figure 12: Sharing tool for students on the UUI

3.3. Topic organisation via Infrastructure Analytics

This chapter presents a short outlook on how teachers' contributions can be organized in a semi-automated way. As shown in D4.6-3D printing and DIY electronics infrastructure analysis and user feedback, the UUI is also able to semi-automatically collect data from the 3D printing and DIY electronics infrastructure. More concretely, specific settings, events and progress data can be harvested from within Snap4Arduino (DIY electronics) and the teacher can input data from the Ultimaker 3D printers.

This data is not only feeding the learning analytics engine, for purposes of understanding and optimizing learning and the environments in which it occurs, but it can also contextualize materials and code examples which are shared by teachers and have been used with a specific version of hard- and software and a specific set of instructions, configuring those systems.

Hence, this information can be a valuable filter once the number of contributions is growing and the teachers or users want to filter content so that their current working environment is matched as closely as possible. For example, apart from the versioning of the 3D Printing software, the following data can also make a difference in order to find out why a given 3D model might not have turned out as expected:

- Nozzle temperature

- Build plate temperature
- Print speed
- Flow rate
- Fan speed
- Retraction speed
- Retraction length
- Type of material

People experienced in 3D printing can then pick up incongruous configurations. All in all, linking infrastructure analytics with a knowledge exchange feature as described in 4.2 has the potential to hugely increase relevance and applicability for users needing to filter shared knowledge.

4 LEARNING FROM EXTERNAL COMMUNITIES

The first deliverable in the innovation management work package (D2.1) underlined the importance of sharing models, technical knowledge and other people's expertise. This is all the more important if we consider the barriers schools encounter in their local environment where dedicated innovation management, providing time and financial resources, is still limited.

4.1. TINKERING VERSUS INSTRUCTION

As put forward by Resnick and Rosenbaum (2013): "The tinkering approach is characterized by a playful, experimental, iterative style of engagement, in which makers are continually reassessing their goals, exploring new paths, and imagining new possibilities. Tinkering is undervalued (and even discouraged) in many educational settings today, but it is well aligned with the goals and spirit of the progressive-constructionist tradition—and, in our view, it is exactly what is needed to help young people prepare for life in today's society". The quote shows how existing preferences in the educational system, e.g. emphasizing content delivery and quantitative assessment, run counter to a pluralism of learning paths including the bottom up experiences of creating tangible objects, the notion of adapting solutions to changing conditions and an essentially different way of accessing STEAM problems.

The pedagogy of making builds on pedagogical schools of thoughts ranging from reform pedagogues to constructivists, from Montessori (Montessori, 2013) to Piaget and Papert (Ackermann, 2001), who emphasized the value of self-regulated learning (van Hout-Wolters, Simons, & Volet, 2000), empowering learners to decide on their learning goals and the ways to achieve them. In such learning settings teachers see their own role primarily in assisting the learner in their learning paths. The focus on instructional interactions in traditional teacher-learner relationships is therefore obsolete.

Learning through making is hands-on learning, where makers learn from observing others, recognise the value of trial and error, and taking part of interdisciplinary and collaborative teams (Bell, 2010; Bruffee, 1993; Kaltman, 2010). In this, making is similar to problem solving and project-based learning approaches. Making includes a desire to produce things more collaboratively by improving design suggestions of others or by simply copying, mashing or personalising existing design elements (Voigt, Montero, & Menichinelli, 2016). Making is thus theoretically and historically founded on "learning by doing" principles (Papert, 1991, 1994). According to the Horizon report, which anticipates technological trends having an impact on educational settings, maker education will have an increasing impact on education in the following years (Becker et al., 2017).

4.2. Collaboration in Instructables Projects

Interviewing teachers about making and digital fabrication in schools (Voigt et al., 2018), we identified a number of barriers to innovating teaching practices, including a lack of knowledge about how to run the technology or how to integrate the use of maker technologies with curricular topics to be covered. Those barriers, in combination with cumbersome decision-making processes and restrictive funding options, could seriously hamper the use of novel technologies in schools. In order to overcome these limitations, educators mentioned several measures such as the use of sharing platforms or groups of likeminded people sharing their experience. From an innovation management perspective, technologies that enabled networking between innovative teachers were largely preferred over knowledge-banking strategies such as best practice collections or 'go-to experts' (Voigt et al., 2018).

In itself, referring to networking and community building as promotional devices of educational purposes is not new. Innovation networks in education can be seen as an amalgamate of Wenger's communities of practice (Wenger, 2003) and Kazmer's idea that knowledge is shaped by learners' membership in multiple overlapping communities (Kazmer, 2005). The benefit that comes with considering communities is primarily based on their purpose giving nature, even though we must be aware of overstating the homogeneity of communities (Voigt, Unterfrauner, & Stelzer, 2017). Wenger argues that throughout life, communities motivate our learning by defining the relevancy of problems and providing orientation in terms of where answers can be found or where previous attempts to find solutions have been unsuccessful. On a more practical level, however, we do not yet fully understand what makes collaboration in communities work (Stoll & Louis, 2007). Kaptelinin (Kaptelinin, 2005) argues that collective activities are structured, directed and motivated by objects, which capture the purpose of networking . Hence, objects in networks help individuals to express themselves in a cognitive as well as affective way – a process Knorr Cetina refers to as „object-centred sociality" (Knorr Cetina, 1997). Taking project descriptions as 'objects' enabling the shaping of knowledge and communities, the following section describes activities related to those objects.

Analysing the evolution of online networks over time, we found that less than 1 % of projects on Instructables involved collaborative authorships (Figure 13, see also video[4]). Hence, even in well established communities, collaboration is not yet the norm.

[4] http://make-it.io/2017/11/10/do-we-need-more-collaboration-for-a-truly-disruptive-maker-movement-first-insights-from-the-instructables-com-community/

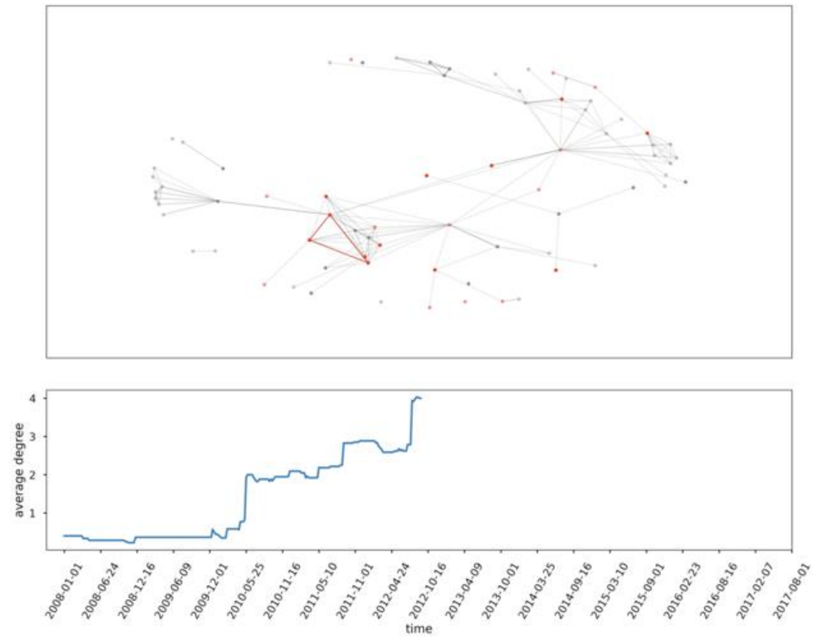

Figure 13: Emergence of a large sub-network of people having collaborated over a period of more than 9 years

4.3. Remixing of Thingiverse Designs

We then analysed a second community, in order to better understand what information was reused and what impact was generated. This time, the focus was on a 3D printing community. Reusing information is key to the continuing development of the knowledge society and the emergence of the Zero Marginal Cost Society, that is the paradigm shift from market capitalism to the collaborative commons (Rifkin, 2014). Rifkin envisioned an era, where competition leads to ever leaner production mechanisms and sharing platforms turn consumers into prosumers as they create, adapt and remix existing designs into personalized designs (Rifkin, 2014). An example of platform collaboration are 3d-printing communities, sharing and remixing their 3D models. Remixing as a form of peer production is also referred to as a shift towards a more collaborative culture, increasing the quality of collaboration outcomes, since members of the 3D printing community can iterate and refine each other's' designs (Benkler, 2006). More generally, remixing describes the practice of "taking ideas and modifying or recombining them" (Nickerson, 2015).

The specific sharing platform we analyze in this chapter is Thingiverse.com, a platform providing reusable designs at an entry-level, as well as meta-models or complete design files using 3D modelling applications such as OpenSCAD, Blender or Fusion360. Whereas the first two file formats are generated by free software, the latter requires a commercial digital prototyping tool, where free licences are granted, but only for educational purposes. By the end of 2017 Thingiverse featured more than 993,850 3D Models or Things and states on its Website to represent the world's largest 3D printing community ('Thingiverse.com', n.d.).

3D printing is a hugely dynamic area, becoming ever more accessible to a growing number of tech-affine tinkerers. 3D printing is also a cornerstone of the Maker movement, which lowers the entry barriers to innovation by enabling fast prototyping and experimenting with ideas (Elisabeth Unterfrauner, Voigt, Schrammel, & Menichinelli, 2017). While declining in price, printing materials are constantly improving, printers become more reliable and the opportunities seem limitless, as indicated in an early cover story from the Economist in February, 2011, which said "Print me a Stradivarius" ('Technology: Print me a Stradivarius', n.d.; Voigt et al., 2016).

The specific background to this chapter is the question whether Thingiverse content can support educators, either by identifying models useful to their specific subject matters (e.g. geometric shapes, miniature models of cells or a Pythagorean cup, showing the transmission of fluid-pressure) or by providing models students could adapt and print themselves.

Being an open platform, Thingiverse.com encourages sharing of 3D models under a Creative Commons license, meaning that all designs can be altered and reused. The ease with which a design can be adapted or remixed is critical in driving the maker movement, where you do not invent from scratch but reuse existing, partly proven solutions (Anderson, 2012). Other features determining sharing and collaboration patterns include the possibility to easily credit original sources, a positive community spirit which supports newcomers and the general usability of the sharing platform, including design categories, detailed search functions or the featuring of high quality designs. Of course, remixing can take different shapes, such as merging two designs, extracting a specific part from a design or simply slicing a design so that it fits a smaller printer chamber or leads to a less error prone printing process. And there are questions that go beyond dyadic relationships between 3d models, such as how often a remix has been remixed, leading to chains or networks of models forming increasingly complex prints.

While there is consensus on the importance of sharing designs in the maker movement, this is less the case for other aspects such as licencing models, e.g. creative commons with or without commercial derivatives, or the way remixing is supported best, e.g. by creating a customizable model or by referring to the original CAD files. Customizable models are parametric designs where some characteristics can be changed without any knowledge of the underlying programming language. Typically, users change the dimensions of an object or the writing on things like key chains. The creation of customizable models is supported by Thingiverse though its Customizer App. The introduction of the Customizer App had a huge impact on the number of designs hosted on Thingiverse. The year after the introduction, content on Thingiverse almost tripled (Oehlberg, Willett, & Mackay, 2015). However, Blikstein (Blikstein, 2013) argues that the 'keychain syndrome' should be of no surprise, since a relatively high 'product value' is achieved with a relatively low 'investment in learning'. Our interest in remixing activities on Thingiverse is primarily motivated by our interest in exploring the platform's potential to provide content in a way that supports educators. The underlying hypothesis is that a model, which has been remixed, has already shown its printability. However, screening the first remixes we quickly realized that this assumption would be incomplete. Thingiverse featured very different types of remixing behaviours, some of which would lead to very innovative, novel outcomes whereas others would mimic the original design with only minimal changes.

Hence, we established three research directions to obtain a more differentiated understanding of remixing:

a) What is the extent to which remixing is already happening? In what ways is the number of sources being remixed related to the innovativeness of the remixed product?
b) What role do other network activities play? Here we are interested in users' liking or downloading behavior, or the way remixing stays within or transgresses nominal design categories.

Finally, can we go beyond the analysis of dyadic remixing relationships, identifying chains of remixes in the quest for more complex innovations.

4.3.1. Varying degrees of innovativeness

As stated by the authors of a recent study of innovation on Thingiverse.com (Flath, Friesike, Wirth, & Thiesse, 2017), reusing existing knowledge is indispensable for the creation of novel designs. Although there is no lack of definitions for innovations, there is a consensus that innovations imply a discontinuity or disruption:

- either in the way a novel product addresses an existing problem or user need or
- because a new, parallel market place is developing, e.g. electronic typewriters, smartphones and currently e-cars can be seen as products disrupting existing markets (Garcia & Calantone, 2002).

This view is very much in line with Schumpeter's classical definition of innovation as 'new combinations of production factors' leading to the creative destruction of incumbent products or production methods. Replacing the incumbent is then less a matter of price – minimizing costs – but it is a capability driven process, i.e. offering new features or better performance (Spencer & Kirchhoff, 2006).

For our current discussion of remixing behaviour specific to a sharing platform of 3D-models the question is whether remixed models include 'new features' or show 'better performances'. For that to answer, it is helpful to have a more fine-grained typology of innovations. A common categorization includes 2 dimensions (Garcia & Calantone, 2002):

- micro versus macro level innovations (referring to the scale of impact, i.e. is it an innovation to a single firm or an entire market) innovations and
- the innovation's power to disrupt technology and market directions.

According to the authors in (Garcia & Calantone, 2002), radical innovations include macro level discontinuities, affecting markets and technologies, and incremental innovations are micro level discontinuities, where it is sufficient if either technology or markets are affected. Hence, the questions we need to add to our research agenda are: 'What added value do users have of remixed designs?' and 'Does this value originate from a model's features or is it more the associated production process of the model that creates the value?'. For example, a 3d model with additional functionalities might exhibit better use qualities, whereas a customizable 3d model drastically simplifies the remixing process (*production process*).

4.3.2. Method and data

This chapter explores data which have been collected through the official Thingiverse API (MakerBot Industries, 2018) during the first 2 weeks of November 2017. The data set comprises 893,383 designs (hereafter also referred to as things or 3d models), which have been provided by 193,254 authors. This reflects an almost complete set of designs as far as designs have been published and were accessible through the API.

In network terms designs are nodes which are connected if design *R*-(remix) uses information coming from design *O*-(original), or put differently R is a derivative or remix of O. It is important to clearly state the technicalities, i.e. on what grounds such a relationship can be established. For example, if the original model is a customizer, then a remix connection with O is automatically established, clearly indicated under the platform's "*remixed from*" section. However, if a user decides to download the SCAD (Solid 3D CAD) file of a design, modifies it and uploads it again, then he or she is strongly encouraged to list the original, but there is no technically enforced mechanism for tracking the remixing of existing models. Similar issues with attribution have been explored within the Scratch programming community, showing that even automated crediting is not sufficient if users feel that a remix is more an act of plagiarism than of remixing, especially if the 'remix' consisted of a minor change of colour (Monroy-Hernández, Hill, & Gonzalez-Rivero, 2011). This implies that the connections between designs need to be seen as an approximation, either because remixers did not credit the original author (false negative) or because a claimed remix is in essence a copy (false positive) (Nickerson, 2015).

Looking at the distribution of remixes on a design level (Table 1), we see a distinctive difference between the number of designs that get remixed (29) and the remixes a design can attract (32,923). In fact, the design including 29 others is a typeface composed of objects from Thingiverse itself, so it is more like a collection of several designs. Whereas the second highest import of designs (26) results in an artistic Buddha figure integrating stylistic elements of movie characters, such as Yoda and Batman. Designs which could attract huge numbers of remixes are largely customizers for key chains (thing ID: 739573) or lithopanes (thing ID: 739573), which are photos transformed into a 3d print, which, if backlit reveals the image. For example, the second most frequently remixed design is a lithopane customizer provided by MakerBot, the company that owns and runs the Thingiverse platform. For this particular case, also the downside of a customizers becomes apparent, the customizer version of this design was repeatedly broken, causing docents of complaints in Thingiverse's discussion forums. The issues could be circumvented by using the offline application of openSCAD, which is open source (OpenSCAD, 2018), but without the ease of remixing within an online application many users felt lost.

Table 1: Remixing on a design level (n=893,383)

Remixing Variable	Mean	SD	50%	95%	Max
Design remixes others	0.56	0.59	1	1	29
Design is remixed by others	0.55	49.55	0	1	32,923

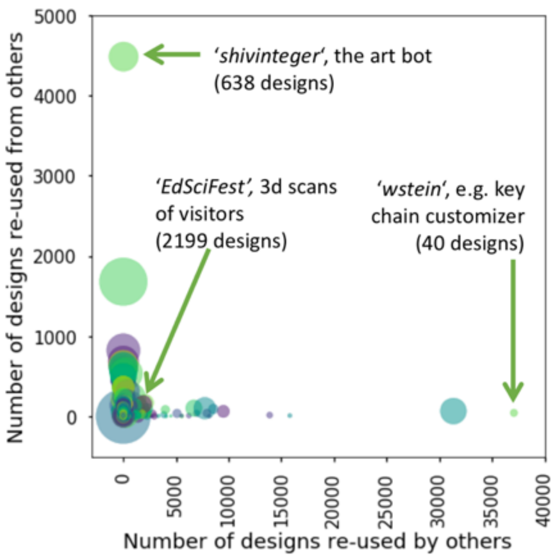

Figure 14: Remixing grouped by users (n=193,254)

The table and Figure 14 fit findings, which state that there are two distinct groups on Thingiverse, one that almost never uses customizers and one that almost exclusively relies on customizers for remixing (Flath et al., 2017).

4.3.3. CUSTOMIZERS, BOTS AND SELF-REFERENTIAL DESIGNS

A second question we are interested in, was whether remixing is an indicator for a design's innovativeness. Referring back to section 5.3.1, where we distinguished between product and process innovation, we would classify remixes of highly popular customizers as process innovation.

Key benefit is the intuitive adaptation of an existing design in a prescribed way. Even though it would be possible to remix a remix into a novel, improved product, this has rarely happened among the top 6 most remixed designs (representing 9.8% of the total Thingiverse network captured). Figure 15 shows two customizers and their remixed remixes, i.e. nodes with more than one connection. The size of the nodes emphasizes the number of connections and the color indicates different design categories. The 'nuts and bolts' design has been uploaded under the design category '*parts*' and was remixed in the '*3d printer accessories*' category. Just like the iPhone case has been also remixed in the '*kitchen & dinning*' and the '*accessories*' category. Behind the iPhone graph the amount of 7,376 nodes, to provide a visual impression of the proportions between the number of times the iPhone case was integrated into a novel design versus the number of times the design was replicated.

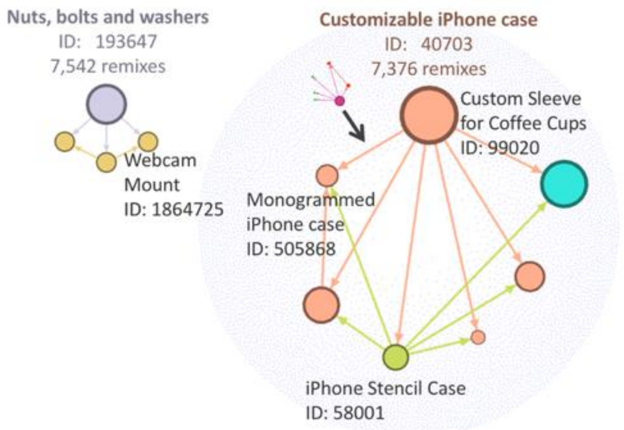

Figure 15: Remixes of two of the most remixed designs with more than one connections

As stated before, design ideas coming from outside the Thingiverse ecosystem could enriched the design of an iPhone case as well, but these ideational imports are rarely explicitly documented. Another source of 'noise' within the network's remixing topology are bots. Although not yet as endemic as in the Twitter community, where the followership of prominent figures consists to 20-30% of social bots (Dickerson, Kagan, & Subrahmanian, 2014). In today's highly interconnected world, Bots tampering with the social web can influence public debate by manipulating the perception of reality among users unaware of how much social media are infiltrated by bots (Ferrara, Varol, Davis, Menczer, & Flammini, 2016).

Thingiverse's most prominent bot is 'shivinteger', with 4,485 remixes (some 0.9% of all network connections), leading the list of the most prolific remixers. Unlike some of his Twitter counterparts, shivinteger's purpose is not to manipulate the 3d printing community, but to produce media art. Randomly selected designs are cobbled together, generating bizarre mash-ups which are then uploaded again. The bot's creations have since been presented at art events and generated a discussion about whether bots can create art or whether their art is in fact spam, as it interferes with search results (Newitz, 2018).

A third phenomenon we discovered was *'self-citations'*, i.e. if the authors of the remix and the remixed designs were the same users, then this was counted as self-citation. This could often be seen if users iterated over their own designs, reacting to user comments, e.g. providing a model with higher resolution or functional changes. Self-citations were also used to indicate a collection of models that belong together, like a nine pieces marble race track (Thing ID: 61049 by user 'cassandra'). Figure 16 shows the complete graph of the track's nine building blocks, where each element references every other element (numbers indicate downloads).

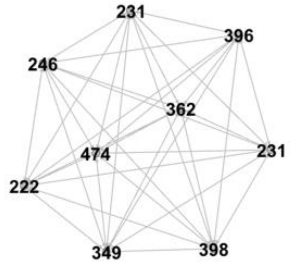

Figure 16: The complete graph of a nine pieces marble race track (Thing ID: 61049 by user 'cassandra').

All in all, self-citing was not a very widespread practice. Only 0.013% of all models (12,389) got remixed by their own authors. The two designs that had the highest number of self-citations (12) were a collection of polyhedral wireframes (ID: 282868) and a printed book of bas-reliefs from the Art Institute of Chicago (ID: 463657). The first example presented a collection of similar things, their author wanted to provide as a single download. Overall, we could see multiple cases where the remix was not primarily about changing or adding actual design elements, but it rather was about increasing the convenience of the reusing process, i.e. having related designs in one place or providing STL files when only SCAD files were available. From a novice user's perspective, SCAD is not as straightforward to print as STL, since it still needs to compile and generate the STL (accepted by most additive manufacturing tools) (Gibson, Rosen, & Stucker, 2014).

4.3.4. A FRAGMENTED VIEW: VIEWS, DOWNLOADS, LIKES AND COLLECTIONS

Part of our research objectives was to explore the interplay between different activities (viewing, downloading, liking, categorizing etc.) and their impact on remixing. By that we want to revisit the boundaries of our interpretations drawn from a network perspective. As stated earlier, networks are based on decisions about what to in- or exclude, and hence they present an incomplete view of the real world. For example, we use the explicit credits given on a design's Thingiverse page as a proxy for real world remixing behaviour.

Table 2, however, shows remixing in comparison to other platform activities. Where we can see that, like remixing, all variables are heavy-tailed.

Table 2: Views, downloads, likes and collections (n=893,383)

Thing Variable	Mean	SD	50%	95%	Max
Views	927	5,883	128	3,619	912,276
Downloads	255	1,542	52	915	342,708
Likes	18	145	1	62	18,248
Being collected	23	289	1	83	220,309
Being remixed	0.55	49.55	0	1	32,923

Hence, given the lack of normal distribution, we used Spearman's correlation coefficient (Figure 17). Due to the extreme values (outliers) of some designs, we discarded the first and last percentile (resulting in 19,508 designs discarded) before calculating the correlation coefficient. First, we can see high correlation coefficients between 'views' and 'downloads' as well as between 'likes' and 'collects'. But what is also apparent, is the very small correlation between out-degrees (i.e. out-degrees are remixes in network analytical terms) and all other variables. We suspect that an influential variable, i.e. a design being a customizer or not, is missing – as it was not available through the API. But as previous research has shown, customizers are much more likely to be remixed than other designs, regardless of their visibility ('views') and appeal ('likes') (Flath et al., 2017).

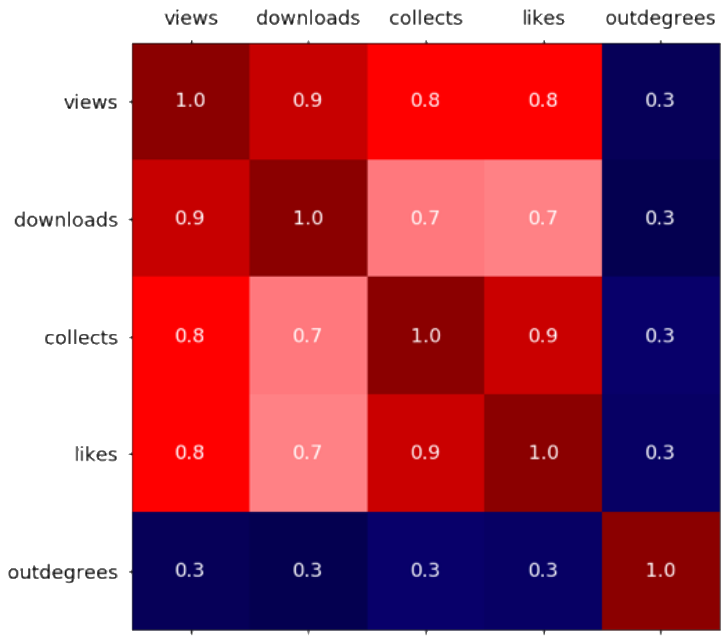

Figure 17: Spearman - Correlation matrix (n=873,875)

4.3.5. Innovation chains

Understanding not only the dyadic relationships between designs, but also pathways and chains of innovations (e.g. the topology of sub-networks) can benefit our understanding about category spanning innovations, iterative design processes and the integration of multiple ideas.

- *Remixing ideas across design categories:* This pattern is related to the non-disciplinary nature of user communities as described in Hippel's 'Democratizing innovation' (Von Hippel, 2005). The underlying rational is that users' innovation behaviour is not restricted by pondering about the commercialization potential of an innovation. Moreover, users, including companies, tend to represent a wide diversity of background knowledge they can bring to the innovation process if needed. Additionally, cross-category innovations tend to explore different contexts and can thereby overcome the limitations of contextually localized search, tapping into spatially confined knowledge (Almeida & Kogut, 1999; Enkel & Gassmann, 2010).
- *Iterations over the same design*: Iterations are typical for prototyping processes. The interaction with the actual prototype opens up the design space and directs users to possible areas for improvement. The actual experience of using a physical prototype or going through an actual prototypical service arrangement, goes often beyond the original product or service specification (Böhle, Bürgermeister, & Porschen, 2012). Schön (Schön, 1995), referring to the role of reflection in designing, explains how materials 'talk back to the designer' and that the materiality of a design is a critical in determining whether a design is accepted or not.
- *Remixing of more than one original idea*: Although we do not assume that remixes of 4 designs are necessarily more innovative than remixes of 2 designs, the nature of innovation (disruptive versus incremental) relates to the breadth and depth of remixing existing knowledge from diverse sources (Enkel & Gassmann, 2010; Flath et al., 2017). Enkel and Gassmann discuss cases, where the ropes of mountain climbers help to innovate

elevator cables or where 70% of a car engine are reused to design a less fuel demanding engine for small business aircrafts (Enkel & Gassmann, 2010).

In Figure 18 we use the example of 'stereographic projection' to illustrate how a mathematically inspired design (1), can spur novel designs across multiple categories, including a projector (2) and a lamp (3). First, 'stereographic projection' is a process for mapping a spherical model to a straight-line grid on a plane, a 3d-model exemplifying this mechanism is the seed for the activities we see below.

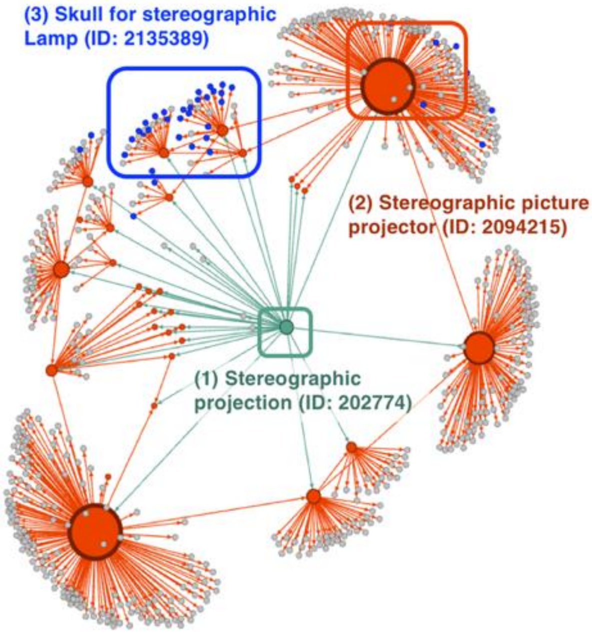

Figure 18: Innovation chains around stereographic projection

At the center is node 202774 (green), whose author provides a collection of designs, visualizing mathematical concepts such as pattern formation, four-dimensional spaces or stereographic projection (Segerman, 2016). All red nodes (e.g. 2094215) are remixes of a mathematical principle, integrated with a projector design and a LED lamp, so that photos transformed into 3d surfaces could be projected against a wall. Whereas the center node has a moderate amount of remixes (36), the project design has more than 200 remixes for one version alone. This is the effect of providing a customizable projector where each user can upload a photo and generate his or her personalized picture projector. Finally, the design of the picture projector is remixed with a skull (from the 'biology' design category).

4.3.6. The value of topologically more complex chains of innovation

The analysis in chapter 5 has shown the variety of remixing behaviors in a network as large as Thingiverse. Some of the dominant patterns, such as the huge number of remixes attracted by customizers are technologically induced, i.e. through the provision of a customizer app, which dramatically simplifies the remixing process. Other patterns, such as bots and self-referential designs are less frequent, buts still show the limits of interpreting recombinations of designs as innovations in the sense of increasing the usefulness of a product or improving a tangible feature of a product.

However, for educational purposes, more complex chains of innovation as describe in the previous section support constructionist and experiential learning more directly, through the need to reiterate, adapt and ensure that the physical product actually fulfills the promises of the conceptual design. In that sense, platform users generating more complex remixes learn to respond to the constraints imposed by the use of specific materials and tools. In the end, complex designs not only promote technical competencies but also personal traits such as self-efficacy (being confident in one's abilities) or creativity (being resourceful in the face of adverse circumstances) (Katterfeldt, Dittert, & Schelhowe, 2015). Hence, knowing how to identify topologically more complex chains of innovation will help to avoid the trivialization of 'making', also known as the 'keychain syndrome', which refers to the fact that keychains are among the most remixed designs (Blikstein, 2013). Yet, going a step further, from the platform owner's perspective, introducing the customizer was a huge success, as it almost tripled the number of designs hosted. Whether or not, future Thingiverse features will allow for distinguishing between trivial and complex innovation chains remains to be seen.

5 INNOVATIVE PRACTICES SUPPORTED BY ECRAFT2LEARN'S UUI

With the previous two chapters we had the benefit of looking at two communities of a considerable size and longevity. This chapter looks at first practical experiences with the UUI during eCraft2Learn's pilots in Greece and Finland. At the time of writing this deliverable, the five stages of the pedagogical model served as organizing frame: imagine, plan, create (including 'program' and 'evaluate') and share (Figure 19).

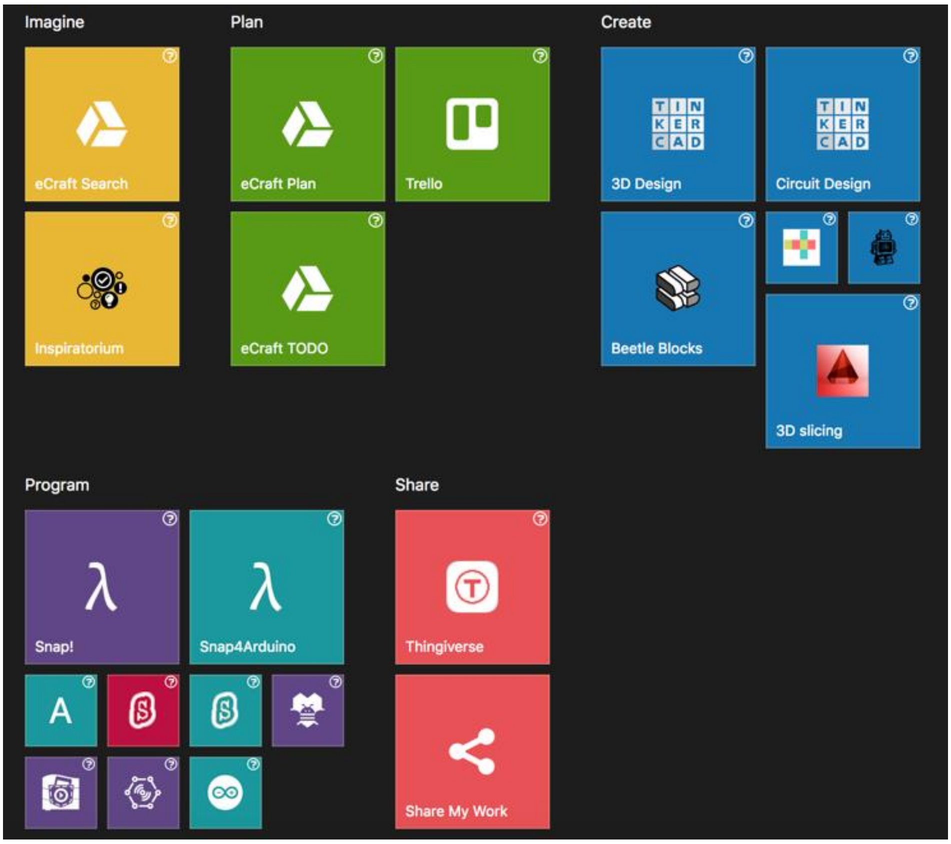

Figure 19: The eCraft2Learn UUI

5.1. Tool uptake

First, we collected a general overview of tool usage. As shown in table three, 12 out of 14 tools have been used at least once and about 60% of tools have been used in both pilots (Table 13). Nonetheless, the aim when providing digital tools to support the craft- and project-based pedagogical approach was not to maximize the number of tools used but to offer a broad variety of tools that could easily support a diverse range of pedagogical scenarios.

Table 3: Overview of tool use in the Finish and Greek pilots, 'x' indicates use

Tool	Finland	Greece
1. Search WWW (list of search items used)	x	x
2. Inspiratorium (log files)	(x)	(x)
3. eCraft Plan (Drawing)	x	(in paper)
4. Trello Project Mmgt.		
5. eCraft Todo List		x
6. 3D Tinkercad	x	x
7. Circuit Tinkercad	x	x
8. 3D Beetle Blocks		
9. 3D Cura	x	x
10. Snap4 Arduino	x	x
11. Thingiverse	x	x
12. App Inventor		x
13. Arduino IDE		x
14. Ardublock		x

Following a brief overview of examples, including comments whenever useful.

Tool 1. Search WWW (list of search items used)

Unsurprisingly, the search tool was heavily used, as its use was also actively recommended as a step in the crafting and making process. Figure 20 shows searching information about world war 2 (left) and robot heads (right). Other examples included looking up the color-coding of resistors and the behaviour of specific sensors in combination with microcontrollers.

Figure 20: Use of the search tool

Tool 2. Inspiratorium (log files)

The Inspiratorium was already described in section 4.1. At the moment we log session IDs and search items. So that we can see what happens in a single session. For example, in one session only 28% of selected item combinations resulted in actual link recommendations. So apparently the mechanism of filtering (more search conditions would lead to less resources) was not entirely clear to that user, as more and more items were added. We can also see which search items persist and which ones change. In the current example 'Halloween' reduced the list of available resources considerably, then more tags were added, leading to zero results. Later in the session, the user replaced 'Halloween' with 'game & light' and 'game & lamp', resulting in 40 and 4 project recommendations respectively.

1	22.08.18	11:55:36 AM	[]								174
2	22.08.18	11:55:44 AM	['do	'how							100
3	22.08.18	11:55:45 AM	['do	'how							100
4	22.08.18	11:55:47 AM	['do	'how	'halloween',	'arduino']					19
5	22.08.18	11:55:48 AM	['do	'how	'halloween']						61
6	22.08.18	11:55:51 AM	['do	'how	'halloween']						44
7	22.08.18	11:55:52 AM	['do	'how	'halloween',	'arduino',	'led',	'craft']			0
8	22.08.18	11:55:53 AM	['do	'how	'halloween',	'arduino']					0
9	22.08.18	11:55:54 AM	['do	'how	'halloween',	'arduino',	'led',	'craft']			0
10	22.08.18	11:55:56 AM	['do	'how	'halloween',	'arduino',	'led',	'craft',	'knex']		0
11	22.08.18	11:55:56 AM	['do	'how	'halloween',	'arduino',	'led',	'craft',	'knex']		0
12	22.08.18	11:55:58 AM	['do	'how	'halloween',	'arduino',	'led',	'craft',	'knex',	'game']	0

Figure 21: Inspiratorium Log File

Tool 3. eCraft Plan (Drawing)

Although planning was an explicit step in the method applied, the execution of planning was not strictly enforced. Teachers reported that often students would go ahead without planning but those who did produced more robust designs, since they became aware of space requirements of the crafting as well as static issues depending on the student's project (see Figure 22).

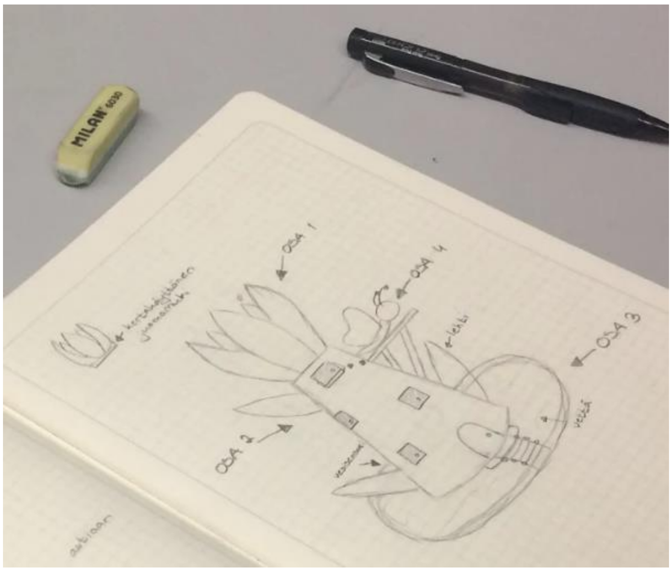

Figure 22: Flower project

Additionally, drawings came in handy when issues with electronics had to be discussed, e.g. the basic connections on a breadboard (Figure 23).

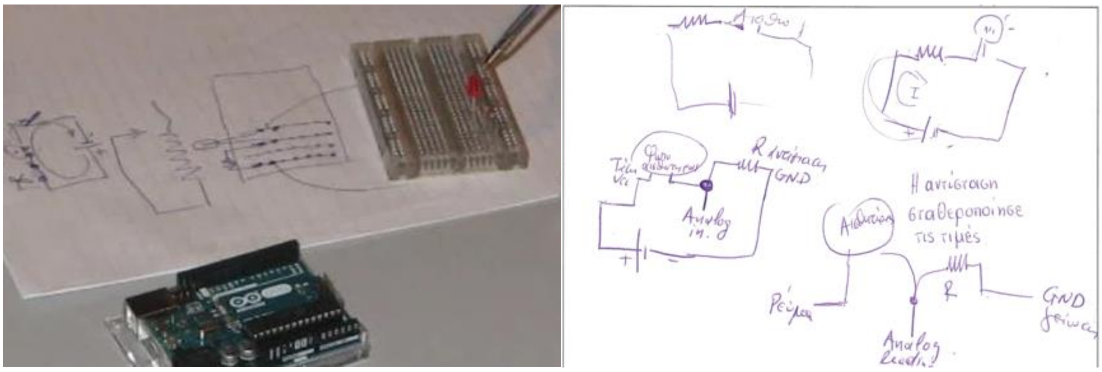

Figure 23: Explaining connections

Tool 4. Trello Project Management

The feedback here was unanimously that the tool in itself is good but overblown for the type of projects implemented in small student teams. Still, a useful option for future project settings.

Tool 5. eCraft Todo List

Similar to the previous tool, the electronic todo list was used to allocate tasks to people and track completion (Figure 24).

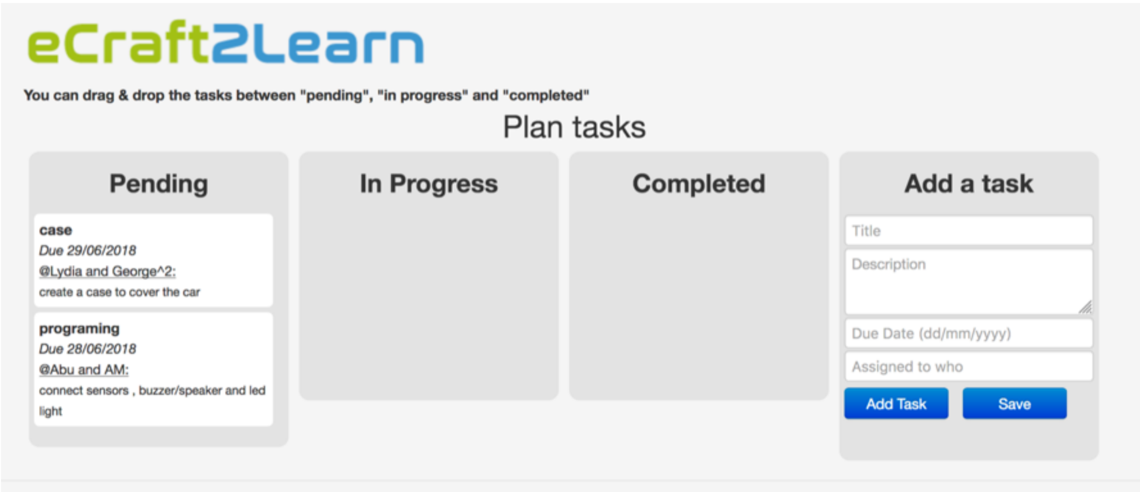

Figure 24: Electronic Tod-List

In this case, the team included students with migration background and used English during their project work.

Tool 6. 3D Tinkercad

The typical name plate exercise (see section 5.3) was also here a good introduction to get to know the bascis of 3d printing. Later a more complex project was implemented, as demonstrated under tool 9, the 3d printing slicer .

Figure 25: Nameplates on Tinkercad

Tool 7. Circuit Tinkercad

A useful tool to check the viability of circuits, e.g. the disastrous effect a 9V battery would have over the LED.

Tool 8. 3D Beetle Blocks

This tool was not used, while others offered similar functionality

Tool 9. 3D Cura

One of the Greek Pilots took advantage of the school's link with an existing bridge building project (Figure 26). Cura allowed for the discussion of 3D printing features such as speed, scale and temperature settings.

Figure 26: Bridge building and 3D printing

Tool 10. Snap4 Arduino

The tool was used as a block-based programming option to program the Arduinos. Simply turning on and off LEDs (Figure 27) was an option just as much as using AI blocks around voice and image recognition.

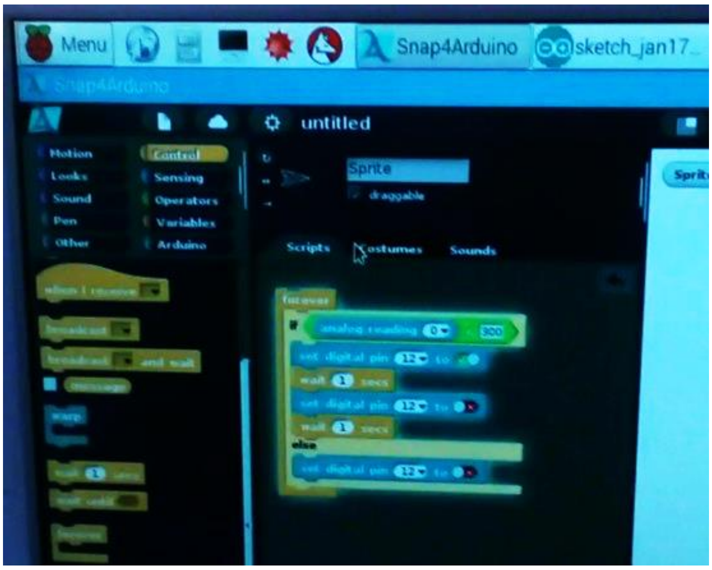

Figure 27: Snap4Arduino, setting a Pin On and Off

Using AI programming blocks when creating a model of a Solar system with all the planets. When a planet was mentioned, an LED corresponding that planet turned on. The speech recognition was added to the physical work of students through Arduino.

Using AI programming blocks to make an interactive map. When a sentence was said, the corresponding LED turned on and after 4 seconds turned off. During the testing of the speech recognition students found out that it is better to use the English default language as the speech recognition was more accurate than when using Finnish language.

Tool 11. Thingiverse

Thingiverse was mostly used as a database for models. In the case below, students could print several planets in their right proportions (Figure 28).

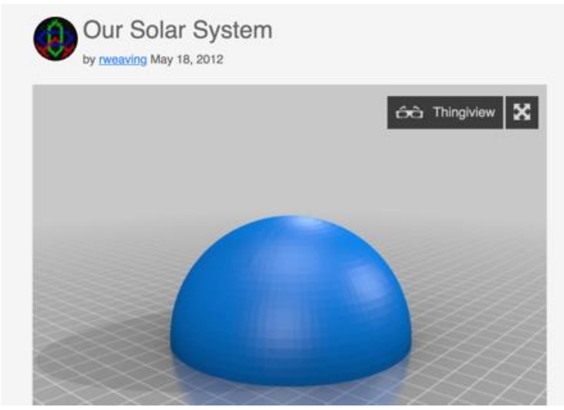

Figure 28:Thingiverse Model of a planet

Tool 12. App Inventor

App inventor is a very attractive tool since it supports remote controlling of a device. In one Greek pilot it was used during three afternoons. An important learning here is complex tools need adequate time allocations (Figure 29).

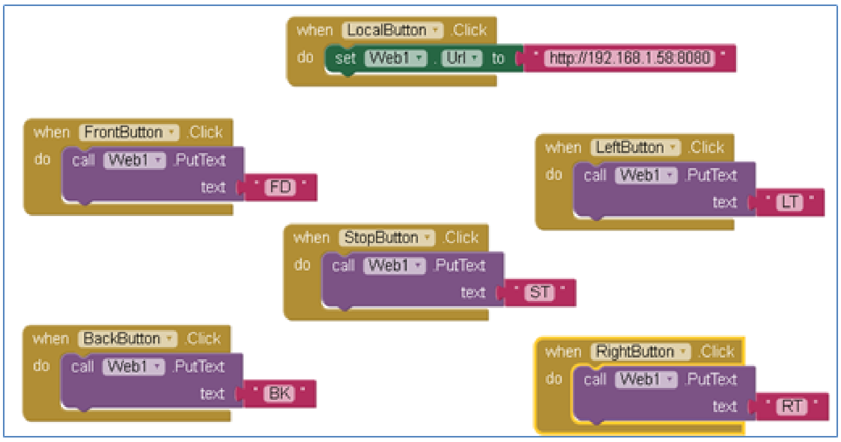

Figure 29: Block-based programming via App Inventor

Tool 13 and 14. Arduino IDE and Ardublock

In the Greek pilots, students preferred block-based programming over text-based editors. However, for our setting, the programming modus was not decisive, and modern online editors allow for switching between 'blocks' and 'code' (Figure 30).

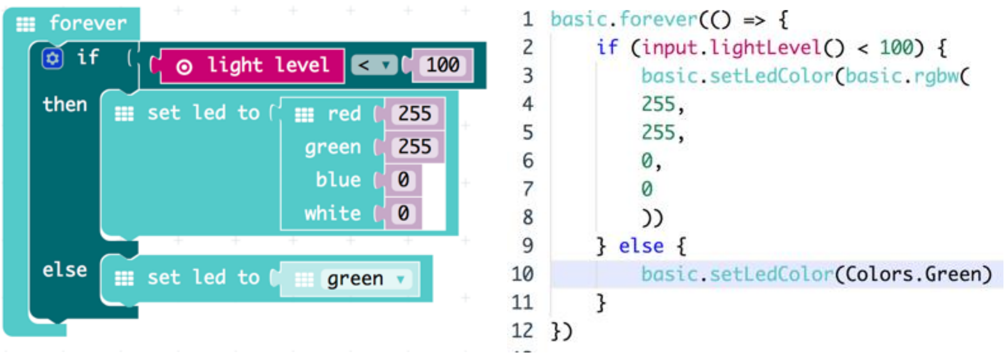

Figure 30: Block- and Text-based programming at the same time

5.2. OUTLOOK: THE USE OF BADGES IN EDUCATION

Another possible innovative approach to evaluating learning within eCraft2Learn are badges: "A badge is a validated display of accomplishment, skill, quality or interest that can be earned in any learning environment. Badges can represent traditional academic achievement or the acquisition of skills such as collaboration, teamwork, leadership, and other 21st century skills."[5]

The badge system aims to develop the self- assessment skills of the students and to help the teachers in the evaluation of the activities related to the eCraft2Learn ecosystem. It is made of a self- assessment phase performed by the students, an evaluation phase performed by the teachers and an achievement phase performed by the system. The achievements aims to increase the students' motivation towards all the steps of their projects.

[5] http://www.learningtimes.com/what-we-do/badges/

5.2.1. SELF-ASSESSMENT

The badge system contains a self-assessment mechanism through which the students can evaluate their progress. Taking into consideration the suggestions of key teacher informants, we identified six categories for self-assessment, corresponding to the various aspects of a digital fabrication project development: building electronic circuits, 3D design, programming, presentation of the project outcomes, quality of the teamwork and originality. Parameters provided for each of these categories guide the students to achieve a reasoned and objective evaluation of their work (Figure 31).

The self-assessment system requires that the students first think about which parameters have been achieved; then, they are asked to assign to each of the six categories a score between 1 and 5 alongside a brief justification for their score. Even if reference parameters are available, the score that the students assign to their work is not necessarily tied to their achievements. That is, the artefact created by the students in their project might not work perfectly, but the student could anyway self-assess a good mark, because they have learned other important skills process; what is important is that students provide justification to their considerations. For this purpose, the interface has text boxes where students should summarise the rationale behind the numerical scores that they assign to their work.

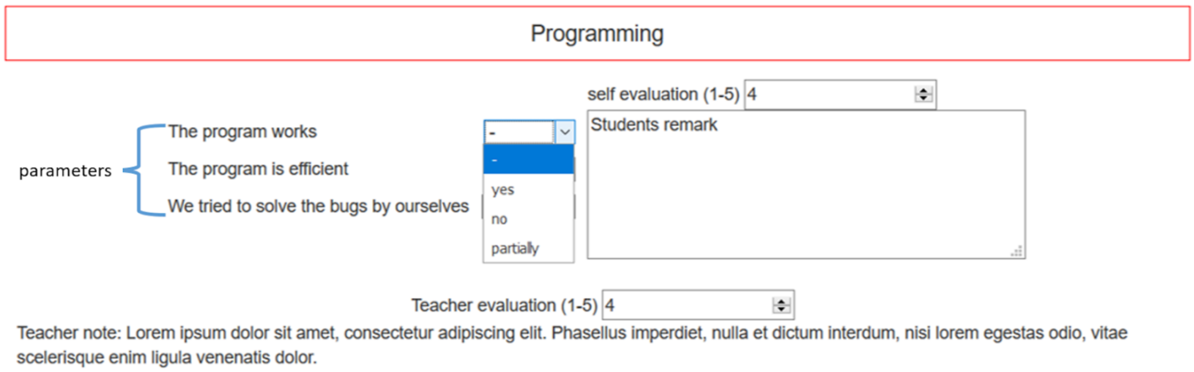

Figure 31: The self-assessment mechanism

The information obtained from these rubrics is precious to the teacher: on the one hand it delivers data on the efficiency of the self-assessment process, and on the other hand it allows the teacher to judge if the learning activity was properly calibrated, offering a comprehensive vision of the strong and weak points of their students. The teacher can confirm the student produced score or assign a different one in the self-evaluation interface, provided that the teacher justifies the change. The teacher modifications and justifications are visible to the students. This transparent evaluation from the teacher and this cyclic process of "self-evaluation↔ evaluation↔ assessment ↔ assessment of the self evaluation" between the teacher and the students are key factors to develop the critical thinking of the students about their learning and the effectiveness of their learning strategies. Nevertheless, this cyclic process, the cognition and metacognition involved in it could result in overburdening the learning process. Therefore, in order to support the learners and keep them engaged in the learning process, we rely on gamification exploiting the quest for more badges and for “more starts” in each badge as a motivating and compelling feature.

5.2.2. IMPROVING MOTIVATION THROUGH GAMIFICATION

The use of game design elements in a non-game context is called gamification (Deterding et al., 2011). Since 2013, there has been a wide consensus on the gamification practice in the educational environment – especially at the higher degrees of education: badges are an example of game mechanics, along with points, levels, progress bars, leaderboards, virtual currency, and avatars. As several studies have reported, the use of these mechanics have a great potential in increasing students’ engagement and in motivating them to learn and train new skills (Dicheva et al., 2015). In particular badges are proved to be effective in triggering competitive motivation (Pirker et al., 2014), in improving learners’ participation (Dominguez et al., 2013) and in enhancing learning, time management and carefulness (Hakulinen et al., 2014). In the eCraft2Learn ecosystem, the scores assigned by the teacher are elaborated and converted into badges (Figure 32). The badges system we designed have a twofold goal. On the one hand, it shifts the attention of the students from the practical activities they have to carry on to complete the project assigned to them, to the skills they are supposed to learn during this activity. This is achieved by the careful choice of the six categories for self-assessment which were defined with the help of key teacher informants involved in the eCraft2Learn project. These six categories visually prompt the students to actively reflect on the fundamental skill they are supposed to assimilate abstracting their thinking from the technical/practical problems at hand. As one can notice, the six categories are divided into technical skills specific to digital fabrication and making activities (such as circuit building or 3D design) and the cross-skills to be acquired (such as presentation capabilities and quality of the teamwork).

On the other hand, the badge system motivates the students to complete their digital fabrication projects and the practical activities associated to the projects . The more activities the students complete and more carefully they implement them, the more badges they will earn.

Figure 32: The badges

5.3. Prospective mechanisms for evaluating bottom-up innovation

Chapter six focused on listing tools within the eCraft2Learn system and showed examples of how they were used. However, innovation management relies on the idea that there is a strategic intend behind the adoption of innovations, which is supported by managerial actions and a fitting organizational culture.

The Innovation Management Process depicted in Deliverable 2.1 included seven steps:

1) Strategy development: identify requirements
2) idea generation: what meets the requirements
3) Screening and evaluation
4) Business check: economic viability
5) Actual product development
6) Testing, commercial experiments
7) Commercialisation

While this is a proven approach in industries, in a school context we found that bottom-up innovations are more promising. Nonetheless, we do not suggest that this is to exempt school management from their responsibility to ensure the efficient use of the already scare time resources of teachers. This can be carried out by: (1) defining the importance of degree of innovation (i.e. the amount of change) required; (2) "managing teachers' expectations about what an innovation can achieve and what not, as well as what sort of effort needs to be made in order to get the innovation working"; and (3) manage the following four areas in order to become more innovative: (a) technical competence, (b) market competence, (c) human resource competence, and (d) organizational competence.

To evaluate the effectiveness of a bottom-up innovation management initiative we suggest the use of Systems Thinking, and more specifically Soft Systems Methodology (Checkland 1999; Checkland & Scholes 1990, Checkland & Poulter 2006; 2010; Mirijamdotter 1998; Salavati 2016). Soft Systems Methodology, SSM, provides a systematic and systemic process and consists of a number of techniques, which enables evaluation related to different perspectives. It is therefore used to learn one's way to improvement, particularly when many stakeholders with various perspectives are involved. The benefits of applying a systems approach is to get a holistic picture that cross traditional organizational boundaries. The benefit of a soft systems or systems thinking approach is in generating an evaluation frame, specific to the particular conditions of a school, the teacher team, existing experiences etc. The overall objective is then to spread craft-based learning innovations as widely as possible and also, à la longue, to find the necessary resources, which can be argued for, given positive evaluation results.

Next a brief description of Systems Thinking and Soft Systems Methodology and an outline how this approach can support the eCraft2Learn project, including a few examples.

Systems Thinking and Soft Systems Methodology

Churchman (1968, p. 231) describes Systems Thinking (ST) as "when first you see the world through the eyes of another", The foundation of ST relies on disclosing underlying assumptions of a specific situation from various perspectives, or worldviews (Reynolds & Holwell, 2010). Checkland (1999) formulates this as understanding the complexity of the world by representing it through a set of connected elements or components to create a whole. Systems Thinking is about making sense of a situation by considering the whole rather than focusing on different parts and hence "gaining understanding by looking at the relationships between things" (Reynolds & Holwell, 2010, p. 8). Systems Thinking further concerns improving a problem-situation rather than defining a static problem and solution for solving that particular problem (Reynolds & Holwell, 2010). In conclusion, Systems Thinking assumes problem-situations that are based on certain (various) purposes depending on the involved stakeholder perspectives. The aim of this approach is to learn about the situation in order to take actions for improving, i.e., changing, the situation (Reynolds & Holwell, 2010).

Systems Thinking includes several traditions and approaches, one of these being Soft Systems Methodology. SSM is an inquiring approach, which focuses on a situation that people, for various reasons, find problematical (Checkland, 2000). One of its fundamental components is Worldview (weltanschauung), i.e. humans' experience of the world in terms of purpose, knowledge, values, expectations, etc. which are developed in various ways, including based on previous experiences (Checkland, 2011).

SSM offers a number of techniques which can be relevant for, in this case, a bottom-up perspective when evaluating innovation management in an educational setting. The first technique concerns defining 'What', 'How' and 'Why' (Checkland & Poulter, 2010), or rather, in the order of **'Why', 'What' and 'How'** (Salavati, 2016). The reasoning behind this technique is to identify what to achieve (Why) by doing something (What) and what methods and activities that should be applied (How); in order to achieve *Why* we need to do *What* by *How*. In terms of eCraft2Learn this could be exemplified as: In order to *manage innovation* (Why) we need to *enable sharing and networking among teachers* (What) by *developing these kind of educational technology features* (How). This technique can then be used from several different perspectives and on different levels where there is possible to have several '*Whats*' to one and the same *Why*, and several '*Hows*' to one and the same *What*. This is illustrated further ahead.

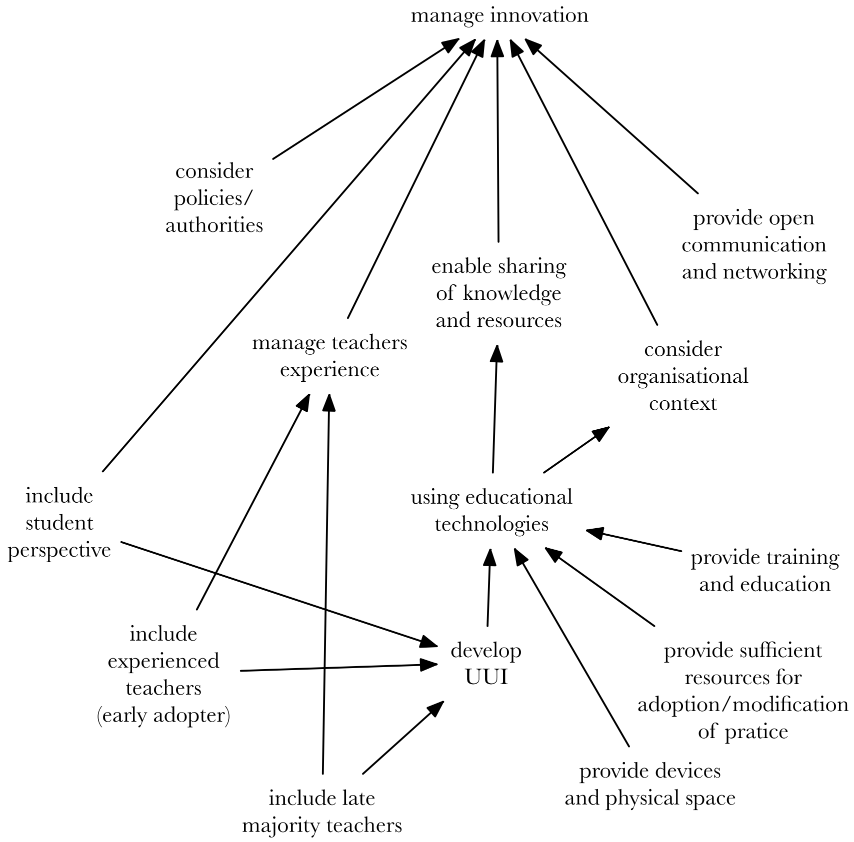

Figure 33: The Why, What and How in Systems Thinking

Figure 33 illustrates a simplified example. At the top center of the figure we have “manage innovation” (*why*), which can be accomplished by e.g. “provide open communities & networking” (*what*), which in turn can be effectuated by “using of educational technology” (*how*). Similarly, “manage innovation” (*why*) can also be accomplished by “include student perspectives” (*what*) by an UUI (*how*), etc. On the next level, “provide open communities & networking” becomes a why, with “using of educational technology” as a *what* and “provide training and education” as a *how* (or the other listed activities as *hows* (“develop UUI”, “provide devices & physical spaces”, “provide sufficient resources for adoption and modification of practice”) on this level of analysis).

For each part (‘Why’, ‘What’, and ‘How’) a model should be developed based on the elements provided by the second technique. The second technique allows to identify a number of human elements relevant to the situation (Checkland & Poulter, 2010, Bergvall-Kåreborn, Mirijamdotter, Basden, 2004). The elements relevant to identify, and later on further discuss, consists among others of:

- Affected - Those who would be affected by the improvement/change of situation (e.g. teachers and students)
- Actors - Those who would carry out the activities to enable the improvement/change process (e.g. teachers who might use students results, if given permission)
- Decision maker - Those who could stop or modify the change (e.g. management supporting or disapproving ‘bottom-up initiatives’)

- Process – stating the improvement/change process (e.g. enabling quick access of group reviewed materials to time poor teachers)
- Worldview – the viewpoint which makes the improvement/change meaningful (e.g. an appreciation of open educational resources and sharing in general)
- Constraints – constraints from the outside that need to be considered and that may affect the improvement/change process (e.g. institutions need to embrace open licensing and a culture of acknowledging failure as a way to learn)

Finally for the evaluation itself, evaluation criteria should be defined in terms of the third suggested SSM technique, Measures of Performance, MoP. The criteria to base the evaluation upon can vary depending on the aim and purpose of the specific improvement/change process and its worldview, however, Checkland and Poulter (2010) suggest:

- Efficacy – criterion for telling whether the improvement/change is successful in terms of reaching the intended outcome
- Efficiency – criterion for addressing whether the improvement/change is achieved with minimum use of resources
- Effectiveness – criterion for judging whether the improvement/change is contributing or helping achieve a longer-term or higher level aim related to the stated viewpoint for the change/improvement process

6 SUMMARY: CONSIDERING DEGREES OF WHITE-BOXING

In this deliverable we focused on open designs, supporting communities (internal and external) as well as specific tools to support innovative learning and teaching practices. Yet, an important benefit of craft-based learning is the versatility and richness of learning that fits under the broad umbrella of making. As we could see in the finish pilots for example, students produced videos to explaining bio-synthesis, including the production of props used in the video. In other instances, programming the microcontroller was easier than getting the engineering work done (Figure 34).

Figure 34: Winch, lifting a box

Considering the strategic intend of eCraft2Learn, which is 'white-boxing' complex technologies and moving from 'technology consumption' to 'technology co-creation', we can see that the project driven character of learning opens up many learning opportunities, where it is teachers' task to create a guiding frame so that learning opportunities do not become overwhelming. Also, given the always existing limitations on time, 'white-boxing' should also be a conscious choice, that can be implemented in different ways. At the end of this deliverable, we would like to show two alternatives to the eCraft2Learn core technologies developed in WP4: (a) the Fabschoolino, a DIY microboard, developed by the WAAG Society[6] and (b) Calliope-Mini[7], a controller based on the positive experiences with the Micro:Bit[8], developed in the UK.

The idea of the Fabschoolino, is to build your own microcontroller, including the same integrated circuit (IC) as used for the classic Arduino Uno board (Figure 35). In the process of assembling and soldering the board, children understand the function of single electronic components, e.g. resistors to protect against high voltages or capacitors to stabilize voltages . The whole process introduces the notion of low cost for electronics and that, depending on the boards purpose, components can be changed, resulting in a more powerful or less energy-consuming board.

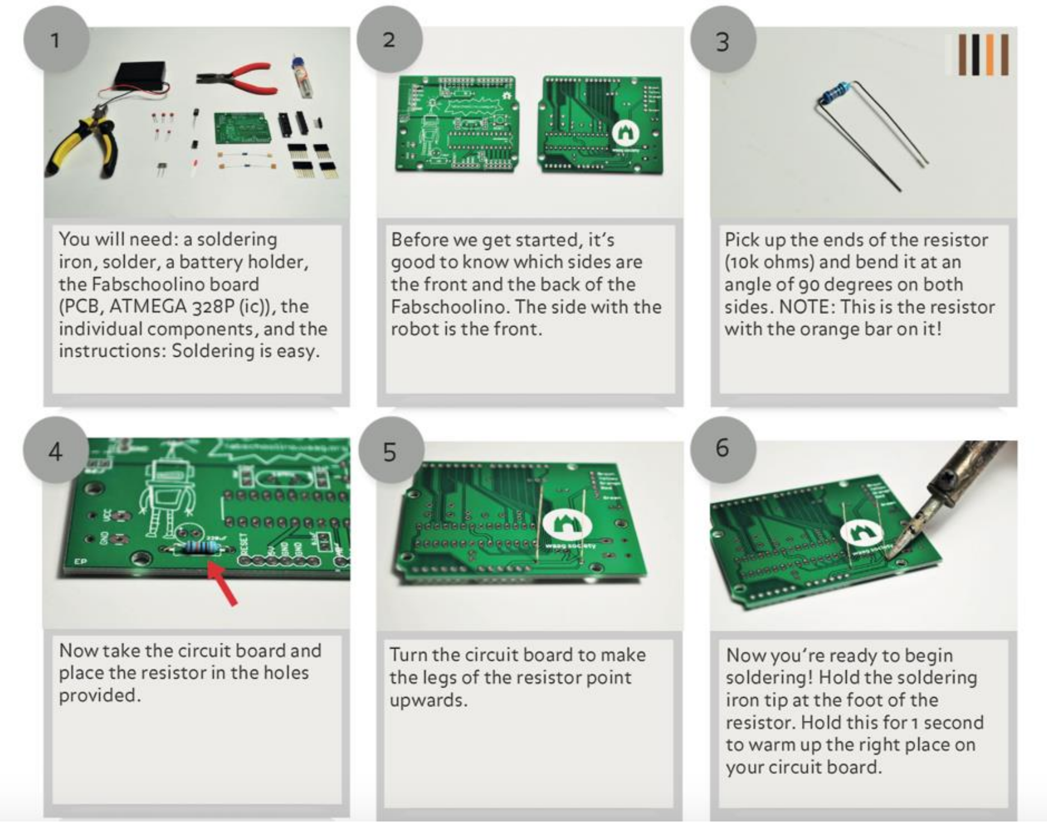

Figure 35: Excerpt of the Fabschoolino assembly instructions for children

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6 https://fabschoolino.waag.org/en/
7 https://calliope.cc/en
8 https://microbit.org/

Whereas the Fabschoolino makes the function of single electronic components more explicit, the Calliope-Mini goes the opposite direction, re-integrating more components (sensors and actors) on the board in order to speed up the applicability of the board in a school context. Hence, unlike the Arduino board, the Calliope board integrates temperature and light sensors, two buttons, a 25 LED display and a speaker (Figure 36).

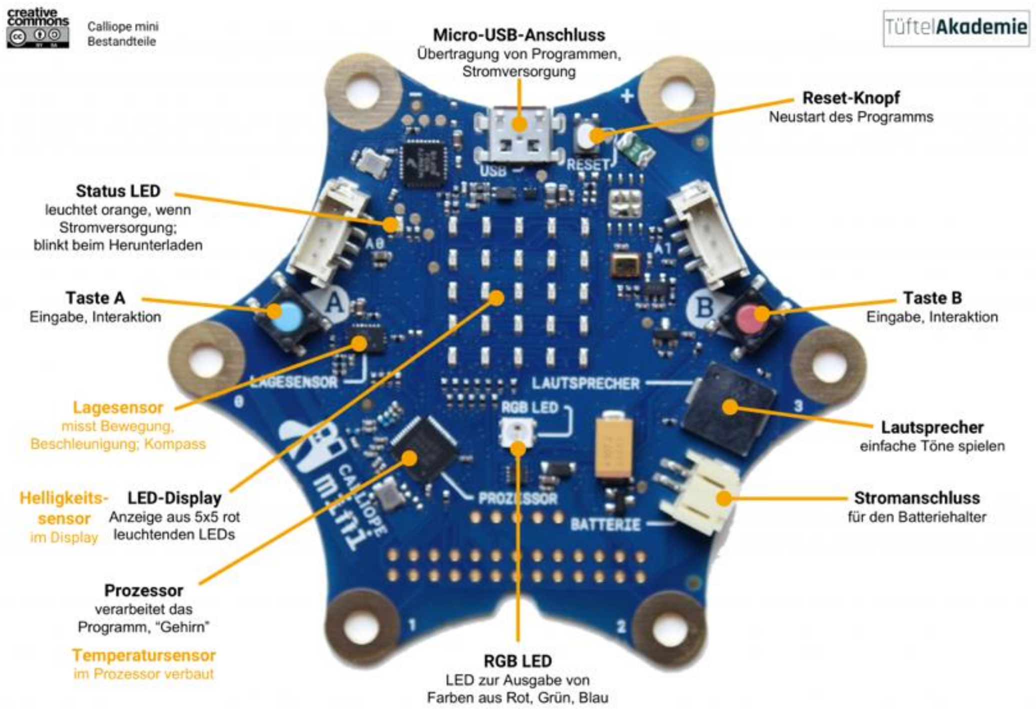

Figure 36: Calliope-Mini with onboard sensors and actuators [9]

From a classroom perspective, the rational for re-integrating components to a board is clear, children receive a single board and can already start programming and experimenting with a wide range of sensors. In the case of similar setup, the Arduino class would need an extra breadboard, jumper cables and the necessary sensors. At this point the Calliope seems more robust, specially for primary school children between 7 and 9 years old.

However, this tendency to re-integrate components is not without drawbacks, since children do not see a sensor actual sensors, the limitations of the actual sensor are less visible. For example, the temperature sensor is within the microprocessor, so that we cannot measure ambient temperature directly. Also, manipulating the gyro-sensor is less intuitive, if we do not know where this sensor is placed on the board.

Lastly, motion is always very attractive for children and also in the context of the eCraft2Learn pilots we see multiple experiments involving motors. However, using a motor often requires an H-Bridge, that is an electronic circuit that switches the polarity of a voltage, so that DC motors can change directions. They also include voltage regulation, since motors require more voltage than the board can provide. That finish Pilot has shown that given proper directions, children can set up the wiring of an H-Bridge external to an Arduino Board. However, the question emerges of how much time should be spent on setting up a

[9] https://tueftelakademie.de/oer-materialien/

motor driver. In that case it might be more convenient if the motor driver is already integrated on the board and can be programmed directly the board (Figure 37).

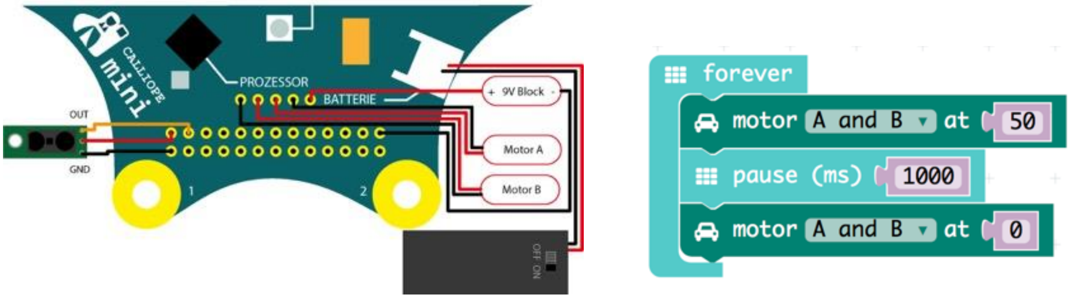

Figure 37: Connecting 2 motors to a Calliope-Mini

All in all, it is good if schools and teachers know about different options, since they impact costs and expertise required to use the technology under classroom conditions. Fortunately all three options (Fabschoolino, Arduino and Calliope-Mini/Micro:Bit) are open source technologies. Beside cost we also found that a supporting community is essential.

Being the oldest board on the market, Arduino has the widest support base. Specially if schools want to extend functionalities with external sensors, Arduino users can rely on a huge user base reporting their experiences and sharing concrete code snippets, this is also reflected by 'Arduino' being the most frequently used publication channel on Instructables.com (see section 4.1.1).

On the other side, Calliope-Mini is put forward by several ministries in Germany and hence the community is more and more sharing materials aligned with the German syllabus and in German language, two critical factors if innovative technologies are to be adopted on a wider scale.

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