Idea Generation and the Shared Epistemic Object of Knowledge in an Artifact-Mediated Co-Invention Project

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Abstract: In Finnish basic education, we are making interventions that engage student teams in collaborative invention (co-invention) processes aimed at knowledge creation. In this paper, we focus on one team of four students aged 13 or 14. We introduce our preliminary findings and a methodological framework designed to analyze and describe 1) the development of design ideas and 2) the shared epistemic object of knowledge that the student team created during the co-invention process. In addition, we seek to describe the role of concrete design artifacts in the ideation process.

Introduction

This paper focuses on the co-invention process of a team of 13–14-year-old students participating in a Co^4-Lab project at Aurinkolahti basic school in Helsinki, Finland. The Laboratory of Co-Inquiry, Co-Design, Co-Teaching, and Co-Regulation (Co^4-Lab) project aims to engage students in collaborative efforts to invent complex concrete or immaterial artifacts, sparking intellectual, technical, and aesthetic challenges. The co-invention projects are designed to offer the students ample opportunities for knowledge creation and innovative thinking. During the projects, the student teams jointly create and build knowledge through processes of collaborative designing and collaborative inquiry into challenging phenomena, by means of scientific and other experiments. Successful co-invention processes, and creating knowledge through them, require the teams to collaboratively identify the design problems related to the task, determine constraints around the possible solutions, and actively engage in and take responsibility for the process (Lawson, 2004; Paavola & Hakkarainen, 2014; Sawyer, 2006; Scardamalia & Bereiter, 2014a). In addition, co-invention processes rely on teachers who, in close collaboration with one another, coordinate the processes and provide appropriate facilitation, guidance, and real-time support for the student teams (e.g., Linn, 2006).

Collaborative design is an essential aspect of the invention and making processes. Co-invention processes involve using traditional and digital fabrication technologies for inventing, designing, and making complex artifacts and thus bring elements of the maker culture (see e.g., Anderson, 2012) to Finnish schools. In accordance with the Learning through Collaborative Designing (LCD) model (Seitamaa-Hakkarainen & Hakkarainen, 2001; see also Seitamaa-Hakkarainen, Viilo, & Hakkarainen, 2010), we construe co-design as communal efforts to create artifacts by solving complex and ill-defined problems through iterative processes, in which design ideas are elaborated and refined through analysis, evaluation, deliberation, sketching, prototyping, and making. The importance of participating in embodied design activities and working with concrete artifacts in learning has been emphasized by many researchers (Blikstein, 2013; Kafai, 1996; Kangas, Seitamaa-Hakkarainen, & Hakkarainen, 2013; Kolodner, 2002). Making is an effective way of engaging students in a design mode (Bereiter & Scardamalia, 2003) that guides them to focus on the usefulness and adequacy of ideas and, moreover, to invest efforts in the continuous improvement of ideas. Artifact-mediated knowledge creation is an emergent and nonlinear process, wherein the actual goals, objects, stages, digital instruments, or end results cannot be pre-determined and the flow of creative activity cannot be rigidly scripted (Scardamalia & Bereiter, 2014b). Inventions can be designed only through repeated iterative efforts at solving complex problems, overcoming obstacles and repeated failures, obtaining peer and expert feedback, trying again, and ending up with outcomes that may not have been anticipated in the beginning. In this paper, our aim is to describe this complex and iterative process of collaborative inventing by investigating idea generation, the evolvement of design ideas, and the role of design artifacts in idea generation.

Co-invention relies on the concept of knowledge-creating learning, which, beyond knowledge acquisition and social participation, involves systematic collaborative efforts in creating and advancing shared epistemic objects by externalizing ideas and constructing various types of intangible and tangible artifacts (see e.g., Paavola, Lipponen, & Hakkarainen, 2004; Scardamalia & Bereiter, 2014). Previous studies of knowledge creation processes suggest that advanced collaboration requires group members to focus on a shared object that they jointly construct (Barron, 2003; Hennessy & Murphy, 1999; Kangas et al., 2013; Paavola & Hakkarainen, 2014). The knowledge creation process may be seen to be guided and directed by envisioned "epistemic objects" that are incomplete, being constantly further defined and instantiated in a series of successively more refined visualizations, prototypes, and design artifacts (Ewenstein & Whyte, 2009; Knorr-Cetina, 2001). However, these epistemic objects of knowledge are often difficult to describe because of their complex nature. In this paper, we seek to define the team's epistemic object of knowledge though the ideas that the team generates and the design problems presented by the team members during the co-invention process.

To that end, the aims, in this paper, are to analyze and describe: 1) how the design ideas evolved from preliminary design ideas to the final ideas, 2) the role of the design artifacts in the ideation process, and 3) what kind of a shared epistemic object of knowledge the student team created during the process. This case study of one student team is a preliminary study, through which we seek to build a methodological framework that can be applied to co-invention processes at a more general level. In the following paragraphs, we first present the co-invention project held at the Aurinkolahti basic school, our research aims, and the research data collected. Then we discuss the methods of data analysis and present our results. Finally, we consider the significance of the findings and the possible future development and applications of the methods tested in this study.

Co-invention project at Aurinkolahti basic school

The present investigators organized a co-invention project with the Aurinkolahti basic school in spring 2017. All of the Grade 7 classes, 70 students in total, aged 13 to 14, participated in the project. The Finnish curriculum for basic education involves compulsory weekly craft lessons until Grade 7. Integrated design and making activities, which are characteristic of Finnish craft education, provide ample opportunities for bringing together STEAM subjects. This enabled us to implement learning-by-making projects as a part of regular curricular activity. For assistance, teachers relied on collegial (co-teaching) resources to negotiate emerging challenges: we engaged two craft subject teachers and three other subject teachers (science, ICT, and visual arts) to coordinate the project. Further, we engaged Grade 8 students to function as "digital technology" tutors to provide additional guidance to the student participants. The Innokas Network[1] offered support regarding digital instruments, materials, and coding initially to the tutor students, who provided peer support to the participating students, and when necessary also to the inventor teams. The teachers were familiarized with the technologies used, as well as given pedagogical support.

The co-invention challenge, co-configured between teachers and researchers, was open-ended: "Invent a smart product or a smart garment by relying on traditional and digital fabrication technologies, such as GoGo Board[2], other programmable devices, or 3D CAD." Before the project, the Grade 8 tutor students arranged a GoGo Board workshop for every participating class, so as to familiarize the students with the possibilities and infrastructure of the GoGo Board and to promote the emergence of ideas on how programmable devices could be utilized in the inventions (cf. Ching & Kafai, 2008). The GoGo Board is an open-source hardware device, developed at the MIT Media Lab, for prototyping, educational robotics, scientific experiments, and environmental sensing (Sipitakiat, Blikstein, & Cavallo, 2004). The actual co-invention project was initiated in February, with a two-hour ideation session, arranged in collaboration with the Finnish Association of Design Learning. During this session, the students self-organized into teams and put forward the preliminary ideas of their inventions. The project involved eight to nine weekly co-design sessions (two to three hours per session) during March, April, and May 2017. The teams also presented their co-inventions at two Co4-Lab events, held at the University of Helsinki.

Research aims and data

This paper focuses on one of the teams that was followed and video recorded during the project. The team consisted of four boys (Markus, Oliver, Leo, and Joel), aged either 13 or 14. They invented the "MGG" ("Mobile Gaming Grip"), a pair of handles that improve the ergonomic use of a mobile phone while playing games. The team worked through the whole process in intensive, self-driven collaboration, all members being highly engaged. They demonstrated high motivation to participate in the project and appeared to enjoy the design process and its epistemic challenges. The team went through a two-stage process, first building a concrete prototype from basic materials, i.e., wood, rubber, and masking tape (see Figures 1 and 2), and then creating 3D CAD models based on that first prototype.

Taking our cues from the ethnographic video data, we formulated three partially interlinked research questions:

1. How did the design ideas evolve from preliminary ideas to the final ideas?
2. What was the role of the design artifacts in the ideation process?
3. What kind of shared epistemic object of knowledge did the student team create during the process?

The video recordings were made using a GoPro action camcorder, placed on a floor-standing tripod, and a separate wireless lavalier microphone. The camera was positioned at a high side angle to capture the team's actions as fully as possible. The first author was also present during every co-design session and made observations and field notes to support in-depth analysis of the data. The video data consisted of nine recorded session, totaling 13 hours and 15 minutes of recordings. The methods used to analyze the video data are explained in the following two sections, together with the results of the analysis.

Figure 1. Prototype of the MGG (Mobile Gaming Grip).


Figure 2. MGG prototype in use.

Evolvement of design ideas and the role of the concrete artifacts in ideation

We analyzed the evolvement of the design ideas by systematically picking out from the video data all ideas that the team generated. The analysis was conducted using the ELAN multimedia annotator (version 5.2). We used an expression of a design idea as an analysis unit. For every idea, we determined the following factors:

- Possible preliminary parent ideas or a theme to which the idea related.
- Whether the idea was included in the final design, i.e., was a final design idea.
- Whether the idea was artifact-mediated.

To gain insight into the role of design artifacts in the ideation process, we formulated three categories of artifact-mediated ideation: 1) the student is looking at a design artifact while generating the idea; 2) the student is holding a design artifact while generating the idea; 3) the student is holding and looking at a design artifact, and pointing to or modifying it while generating the idea. During the analysis, the second category was removed, as it did not occur in the data. Based on the analysis, a network graph of the design ideas and their evolvement (Figure 3) was generated using the Cytoscape[3] network visualizing software (version 3.6.0).

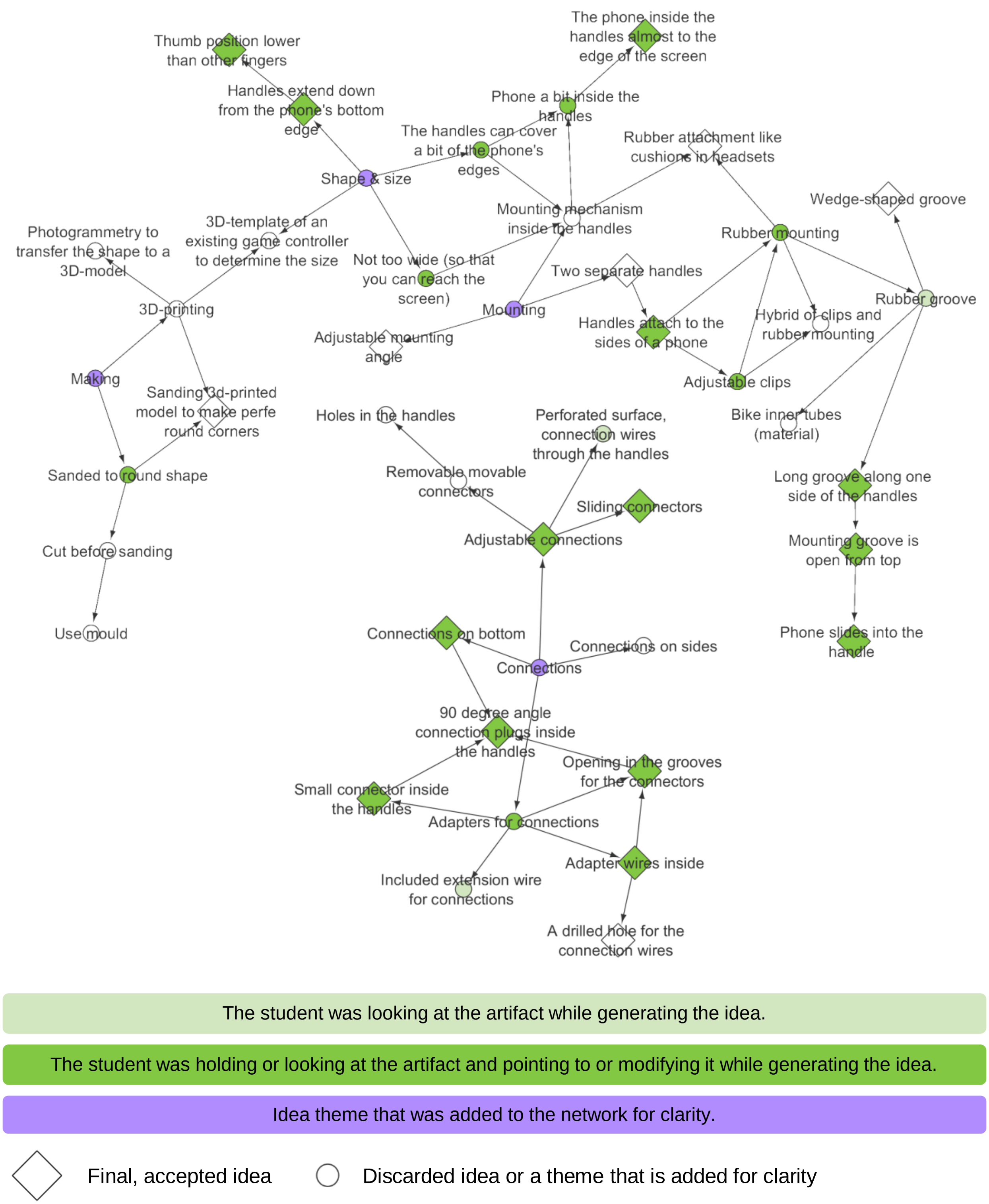

Figure 3: Network of the evolvement of design ideas and the role of design artifacts in it.

The visualized network of the evolvement of design ideas reveals how the team developed their ideas through an iterative process. The preliminary ideas, such as having two separate handles, using adapters for audio and charger connections, or using 3D printing as a method of making, triggered the impulse to generate more refined design ideas.

The arrows in the network graph represent the direction of the ideation process, leading from preceding parent ideas to new ideas. Some of the parent ideas were combined in the ideation process, and some were rejected when new ideas emerged. The idea network also demonstrates the large number of individual ideas that were incorporated into the final invention.

The role of artifacts in idea generation also emerges from the visualization of idea development (Figure 3). The green color identifies the ideas that were generated while the team members were focusing their attention on the artifacts. More than half of the ideas were artifact-mediated, and in most cases the artifact was the center of attention, being tinkered with or modified while the idea emerged. An even larger proportion of the ideas that were incorporated in the final invention were artifact-mediated.

Describing the team's shared epistemic object of knowledge

The close collaboration within the team, as well as the democratic nature of their teamwork and decision making, indicated that the team members clearly shared the same epistemic target object during the whole process of active development (see Riikonen, Seitamaa-Hakkarainen, & Hakkarainen, 2018; cf. Engeström, 1992; Paavola & Hakkarainen, 2014; Seitamaa-Hakkarainen & Hakkarainen, 2001). During the idea evolvement analysis, it became evident that the network of ideas in itself reveals more profound and wider concepts of knowledge than just themes of design ideas.

However, the network of ideas does not reveal the whole nature of the team's epistemic object of knowledge. It provides the answers to the design problems, but the complexity of the design problems and the knowledge work required to solve these remain hidden. To describe the team's epistemic object through the themes around which the team created knowledge during the project, a second round of video data analysis was conducted. In this round, we isolated the expressions of design problems and the conversations preceding the ideas and analyzed them by methods of qualitative content analysis. This enabled a model of the team's epistemic object of knowledge to be constructed (Figure 4). The model consists of four interlinked themes that the team considered and developed during the process, within the uniting theme of mobile gaming. We next present our observations of the interlinked nature of the four themes and the complexity and sophistication of the epistemic challenges that the team faced, drawing on samples of the discussions among the team.

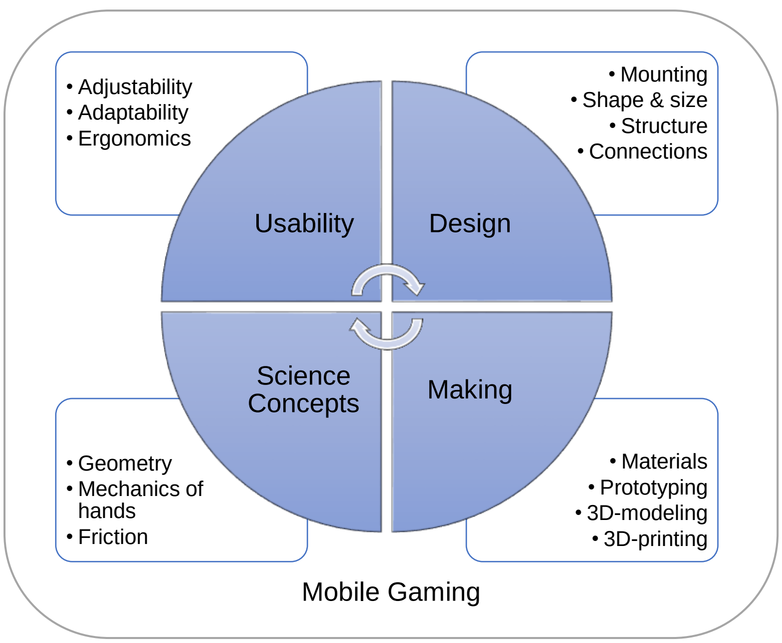

Figure 4: Model of the MGG team's epistemic object of knowledge.

The following conversation demonstrates the intertwined nature of the concepts that formed the team's epistemic object, as well as the versatility of thinking that was required from the team during the co-invention process. The conversation triggered the determination of the size of the handles on the basis of considerations of usability and the mechanics of hands. During the conversation, the team also defined two design constraints: the target group for whom the handles are meant and the space that has to hold the mounting mechanism that attaches the handles to a mobile phone. Setting these constraints established the foundation for more refined knowledge work and ideation.

> *Oliver: We should think about the size... if it were here like this* [gestures to others to demonstrate the size and shape], *could you still reach the screen easily enough?*
>
> *Others: Yes, maybe.*
>
> *Oliver: So, then it should be about like this* [draws a shape around his phone].
>
> *Joel: It's not usual to have something important in the middle of the screen. Although in Geometry Dash there is that practice thing there.*
>
> *Oliver: I don't know if that matters. Who plays Geometry Dash with these anyway? I think that these are more like for driving games and for FPS games that you can't play conveniently on a mobile phone.*
>
> *Oliver: Now, if it's like this, we have this much space for the things that will hold the handles in place. So, we need something like...*

In co-invention processes, the support provided by teachers to the teams is essential (cf. Linn, 2006). However, owing to the complex and unforeseen nature of the design problems, the teacher often becomes a member of the team, providing expertise to the team but unable to provide definite, pre-determined solutions. The teacher must engage in knowledge creation with the team, thereby democratizing the relationship between the teacher and students. The following sample demonstrates the role of the teacher in ideation as an expert member of the team. The conversation further reveals how an artifact, a hearing protector headset, which was unrelated to the theme of the co-invention, acted as an inspiration source for the rubber mounting system of the handles. The teacher's expertise then enabled the idea to be transferred into a practical design solution. From the viewpoint of knowledge building, this sample is also interesting, because during the conversation a science concept, friction, became incorporated into the co-invention process. This conversation took place between one team member and the teacher. Other team members were present during the conversation and took part in it at a later stage.

> *Oliver: We thought we would do something like this. We need something that, you know, holds the handles in place. We think it could be something like this, that the phone fits into, and it holds the phone in place.* [Demonstrates the idea by inserting the phone between the ear cushions of a hearing protector headset, see Figure 5]
>
> *Teacher: Yes…*
>
> *Oliver: But we don't know how to make it yet.*
>
> *Teacher: It could be rubber… some sort of grooves. We could try to make those from a bike inner tube or something like that. Like, if you push the phone in, friction holds it in place. Could it be wedge-shaped?*

Figure 5: A team member tinkering with his phone and a hearing protector headset.

During the co-invention process, the team was able to identify design problems and use them to direct their process. The following conversation demonstrates one such incident. In addition, it demonstrates how concrete artifacts help to define design problems. Furthermore, this conversation highlights how the team posed epistemic challenges to themselves. The team could have decided to design the handles for one phone model only as an easy solution to the problem, but they decided instead to seek an adjustable solution.

> *Oliver: The problem is that this [the audio plug] can be in different positions. The charger connector is always in the center on Android devices, but this audio connector is a problem. I don't know if we should make such handles that you cannot use the audio connector in all mobile phones.*
>
> *Joel: In my phone the audio connector is here.*
>
> *Markus: And on my phone, it's on the bottom.*
>
> *Oliver: So, it's a problem. Phones have the connector in different spots. […] Could we make the connection adjustable? So that it slides or something like that...*

The team also innovatively strove to combine traditional making by hand and new digital technologies. For example, in the next conversation they ideated how they could create a 3D model using a concrete handmade artifact and photogrammetry.

> *Joel: I think it would be fun if we could take lots of pictures and create it [the 3D model] from those. You know, make the shape using modeling clay, then take a lot of pictures of it and transfer that to a 3D shape and then edit it.*

We also observed theoretical scientific concepts emerging as a result of knowledge creation. This final conversation sample shows how a theoretical mathematical concept surfaced through the knowledge creation. Before the conversation, the team had already made the prototype of one of the handles, but now they had to solve how to make the second one so that it would be symmetrical with the first. In this case, the theoretical mathematical concept was the formation of a round shape when the number of sides of a polyhedron approaches infinity.

> *Markus: Can I sand this?*
>
> *Oliver: Yes…or wait! We can't begin to sand it to a round shape now because we do not know how we can then make those symmetrical.*
>
> *Oliver: If we first, you know, begin to remove like corner pieces from it and gradually make it rounder and then finally sand it to the round shape, then it won't differ so much from the other one.*

Discussion

In this paper, we aimed to analyze and describe 1) how design ideas evolved from preliminary ideas to the final ideas, 2) the role of concrete design artifacts in the ideation process, and 3) what kind of a shared epistemic object of knowledge the student team created during the process. This case study of one student team is a preliminary study, through which we seek to construct a methodological framework that can be applied to co-invention processes at a more general level. In this discussion, we appraise the results obtained and reflect on how to further improve and deepen the analysis.

The visualized network of idea evolvement (Figure 3) reveals the multifaceted and iterative nature of the team's idea generation process. Ideas were being generated, analyzed, and thus accepted or rejected during the ideation process. Furthermore, the ideas evolved through an iterative process of combining and modifying design ideas. Although the team's co-invention in itself may seem simple, creating it required a significant amount of innovative thinking and solving of complex design problems. Coming up with the final design ideas took several stages of ideation around multiple themes. The number of individual design ideas that formed the final invention was astonishing and signifies further the large quantity of epistemic efforts required to create the invention. The role of the design artifacts in the ideation process suggests that artifacts have an important role in stimulating ideation and knowledge creation (cf. Ewenstein & Whyte, 2009; Knorr-Cetina, 2001). In particular, the often artifact-mediated nature of the ideas that were incorporated into the final design raises interesting questions regarding the significance of artifacts and concrete making when ideas are being refined and developed.

The team's epistemic object of knowledge began to surface from the network of idea evolvement. When combined with the expressions of design problems and the conversations preceding the ideas, we were able to form a model of the epistemic object as a framework of four interlinked concepts, within the context of the theme of mobile gaming (Figure 4). It is interesting how versatile and sophisticated were the concepts of knowledge that the team had to handle, ranging from concrete making to theoretical scientific concepts. Being able to form a model of the epistemic object helps us to consider what kind of learning takes place during co-invention processes. The fact that the team took on epistemic challenges beyond what was required or absolutely necessary is a significant finding in itself.

Overall, we believe that the analysis methods used in this investigation were successful and provided interesting and rich results. To gain further insight into the ideation processes and the roles of design artifacts therein, it may be beneficial to incorporate investigation of the roles of individual team members into the analysis. Our aim, in the future, is to further develop this methodological framework and apply it to larger video data, with a view to obtaining results that are more generalizable.

Endnotes

1 The Innokas Network is a collaboration of forward-looking schools, universities, and companies focusing on children who are learning 21st-century knowledge and skills. Innokas aims to find ways to make creativity, innovation, and technology part of everyday schoolwork. Innokas's thinking is based on the Innovative School concept, in which the school and its surroundings are seen as a holistic network of learning environments improved by technology. The Innokas Network is coordinated by the Department of Teacher Education, University of Helsinki, by the City of Espoo, and by six sub-coordinators from Finland. Since 2011, over 40,000 students, teachers, parents, learning technology companies, and other stakeholders all over Finland have participated in our network activities. More information about the Innokas Network is available at https://www.innokas.fi/en/.

2 http://gogoboard.org/

3 http://www.cytoscape.org

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