Report 3.2: Describing the Serious Game Design

HAPKIDO
Work Package 3: Governance

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Summary

The continued development of quantum computers pose a risk to public key infrastructure systems (PKIs). PKIs is one the most ubiquitous cybersecurity systems, and they are employed by public sector actors like governments, as well as private sector actors like banks. Within the scope of this report, there is a specific focus on the Netherlands and the impending there quantum transition there. This report describes the design of a serious game that can facilitate actors in the transition to quantum-safe (QS) PKIs. It does so, by firstly exploring the contexts of the transition from a governance and policy perspective, highlighting the differences in approach to quantum-safety as well as quantum innovation, between academics, practitioners, and policy makers. Secondly, the report will cover the methodology used to uncover the critical elements for the design, such as design requirements and design principles. Moreover, the report also examines the differences between one unsuccessful and one successful prototype of the game. Thirdly, the report touches upon the theories underlying the game, and lastly the report provides a walk-through of the game in its current paper form. The reports concludes that the game design provides a theoretical contribution to collective action theory through extending the theory into the socio-technical sphere and providing empiric data for the mapping of ontological and epistemological perspectives within a cybersecurity perspective. Furthermore, the report concludes that the success elements for a serious game that can facilitate in the transition to QS PKIs are the seven design requirements found in the development of the game, which are 1) knowledge-sharing, 2) meeting space, 3) interaction, 4) increased comprehension, 5) neutral ground, 6) awareness, and 7) next steps. Of these requirements, the game design presented in the report failed at achieving 7) next steps, and it is concluded it is due to a failure in the immersive experience of the game, which can be contributed to the game being to macro level in its approach and needing to improve its narrative structure. To improve these points, the report suggests bringing the game down to a meso level and utilizing more specific cases in the game.

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Introduction

The impending transition from current *public key infrastructure systems* (PKIs) to quantum-safe (QS) PKIs is slated to be a highly complex transition. The transition will be founded on knowledge surrounding quantum computing, cryptography, cybersecurity, organizational management, law and policy, and technology governance. For each of these fields an expert level of knowledge will be required to answer the many questions the transition will force us to find answers to. However, there is not one person who can claim to be an expert in every single one of the fields above. This is largely, due to the fact that the timeframe required to specialize across such a multitude of fields is exuberant, and the complex intersection of these specializations has not been required before. Therefore, due to the high level of complexity in this transition, it is paramount that experts and transition actors collaborate to solve the puzzle of this transition. However, from a governance perspective, the system of users for PKIs is largely decentralized, with a handful of national and international key regulating bodies, depending on the country. For the Netherlands, there is one national regulating body, which is Logius, who functions as an authority on PKIs, but only for the public sector. However, PKIs is used in both the public and private sector. Internationally we have actors such as the *Internet Engineering Task Force* (IETF) that publishes standards for PKIs and the *National Institute of Standards and Technology* (NIST), who research, determine, and publish standards for technologies related to PKIs, such as cryptography. When observing the Netherlands as an example, there are PKIs users across the public and private sectors that rely on the secure connections provided by PKIs to function, low awareness of the threat to PKIs and the impending transition, and one governing body whose authority only extends to the public sector and does not have hard, enforceable power. With this it paints a clear picture of a complex transition that is going to require a high level of structure and collaboration, which are two qualities not currently found in the ecosystem of PKIs in the Netherlands. To overcome this hurdle to the transition, HAPKIDO has proposed creating a serious game that can help facilitate users in the transition. A serious game in essence is a game that does not seek entertainment as its main purpose (Bellotti et al., 2010). More specifically, the game proposed in this design falls under the subcategories of educational games and simulation games, which are descriptively named as they seek to educate players on a topic and simulate a real-life scenario within the framework of a game (Crookall et al., 1987; Kara, 2021; Riopel et al., 2019). The HAPKIDO game described in this report seeks to create awareness amongst transition actors related to PKIs in the Netherlands, establish readiness, and facilitate a general level of comprehension of the complexity of the case. For a game to be able to assist in facilitating a transition to QS PKI, the game seeks to be able to create impact across three goals. These goals were chosen based on the requirements articulated by experts, theoretical grounding, and tendencies observed in the field. These goals are awareness, comprehension, and collaboration. The game seeks to be able to impact the players across these three elements, to such an extent that the knowledge and insight gained from the game can extend into real life. Therefore this report asks: What is the design of a serious game to facilitate in the transition to quantum-safe PKIs? Since the design of the game is grounded in academic theory the report also asks as a sub-question: What is the theoretical contribution of such a game? The report below will be divided into four overall sections. Firstly, the report will go into the research methodology used in creating the game. Secondly, the report will expand upon the theoretical grounding for the game, thirdly, the actual design of the game will be presented and explained, step by step, and lastly, the report presents its conclusions.

Background

The debate surrounding responsible quantum innovation spans far and wide, but often center on policy implications, application possibilities and risks, developments, and responsibilities to name a few. For this report, we are looking at the matter from a governance perspective, which often correlate with the policy perspective and sometimes the legal perspective. The debates surrounding quantum innovation are engaged in equal turn by both policy makers and academics alike, discussing what the best ways are to foster continued innovation and sustain the impending transition. The British government promotes a pro-industry stand point, arguing that by providing a gentle and supportive framework for industry it will be able to rise up and meet the demands quantum computing will create as it continues to develop (Regulatory Horizons Council, 2024). However, other researchers caution against this approach, arguing that our handling of quantum technologies should be proactive rather than responsive (Bruno & Spano, 2021; Kop et al., 2023). Kop et. al. (2023) suggest a list of responsible quantum technology principles, that they nest within a larger framework for quantum innovation, which promotes safeguarding, engagement, and advancement. These principles include recommendations for proactively anticipating malicious use of quantum computers, purposely seeking out international collaboration to establish shared values in the transition to eliminate a hyper-individualistic winner-takes-all mentality, and considering the planet as a socio-technical environment capable of functioning on quantum technology. Furthermore, they recommend creating an ecosystem surrounding quantum to increase awareness, and including stakeholders through keeping an on-going debate (Kop et al., 2023, p. 12). The suggestion to take an anticipatory and preventative approach to quantum innovation is also shared by other researchers, who suggest that we begin legislating on the supranational EU level regarding security issues related to emerging quantum technologies already now, to set a wider precedent that can aid us further down the road (Bruno & Spano, 2021). Remaining within the supranational EU perspective, the recommendation for prioritizing international collaboration is frequently stressed by researchers. Rodriguez (2023) argues that we need a quantum safe agenda for all of Europe and not just individual countries. One of the European Union's main priorities is accessibility and harmonization within the member states and therefore it is imperative that we prioritize collaborating across borders to solve our collective issues and create a handful of applicable solutions together, instead of each country having to invent their own solution (Rodriguez, 2023). Moreover, leaving each county to invent their own solution would most likely create a disparity between the member states, where some countries are better equipped to solve the issues, both financially and from a capacity perspective. Above all, there is no reason for each country to put in the time and effort to create solutions, when the work can be delegated and harmonized at the supranational level (Grangier et al., 2024).

Taking an even higher macro level perspective, considering our planet as a socio-technical environment is an interesting proposition, and one that other researchers have expressed similar ideas to. In considering the planet as a socio-technical environment, we can consider our digital infrastructures and establish them as central to the functioning of society on both the national and the supranational level. Some researchers consider them as a *shared common resource* (Shackelford, 2020), meaning it is a resource which is shared by a community that relies on what can be gleaned from the resource. Within a cybersecurity perspective, researchers are also starting to consider cybersecurity as a *shared public good* (Kianpour et al., 2022), which means a resource which in principle is open to all and does not experience scarcity. Both 'shared common resource' and 'public good' are terms that belong to collective action (CA) theory, which is one of the theories underlying the design for the game explained in this report. Collective Action (CA) theory centers on social systems in which a group of actors collaborate in order to manage a shared resource (Ostrom, 2009). CA has most commonly been applied to ecological cases and has been most famously employed by Elinor Ostrom, who won a Nobel prize for her work in applying CA to study how the earth's wealth of shared goods can best be governed sustainably. More recently, CA has also been extended to other fields, such as cybersecurity (Shackelford, 2020) and serious gaming (Bourazeri & Pitt, 2014b). Upon extension to new frontiers, such as socio-technical spaces, researchers have found idiosyncrasies from the traditional 'rule' of the theory when observing how it behaves in new spheres. This includes research that indicates digital communities have a higher propensity for providing collective good, corresponding to the size of the group. This means the bigger the group, the higher the propensity. This is in different to what Ostrom found in her study of the theory, wherein she observed that the smaller the group, the higher the propensity for collective good (Dejean et al., 2010). These idiosyncrasies suggest that applying the theory to these new spaces could lead to significant contributions to the continued development of CA theory. As such, our research strives to provide a theoretical contribution as well as real-world impact. Furthermore, CA has also been utilized in serious gaming previously on topics of urban design, water management, climate change, forest maintenance, knowledge management, and socio-technical systems, to name a few (Beattie, 2020; Bourazeri et al., 2017; Bourazeri & Pitt, 2014b, 2014a; Constantinescu et al., 2017; Meinzen-Dick et al., 2016; Siepman, 2017). Serious gaming as a concept pertain to all games which are not made for entertainment purposes (Bellotti et al., 2010), and its subgenres pertain to topics like educational games (Kara, 2021) and policy games (Duke & Geurts, 2004). The game design proposed in this report lies at the intersection of these two genres and under the broader umbrella of serious gaming. Collective Action Theory is helpful in targeting the elements brought up by the policy game perspective by supplying a lens through which we can approach the concept of group behavior and managing shared resources within a group with multiple levels.

However, within the element of learning, an alternate theory was needed to supply our understanding of how to disperse knowledge and how comprehension is best achieved. For this we relied on hermeneutical theory, and specifically the hermeneutical circle and real-time hermeneutics. The hermeneutical circle pertains to the learning process of acquainting and re-acquainting oneself with a topic to gain a deeper understanding (Suchting, 1995). Real-time Hermeneutics pertain to act of the creating and immersive environment wherein the participants can negotiate the terms of the scenario they have been presented with (Arjoranta, 2011). This term specifically pertain to using hermeneutics in a game environment, wherein the players can traverse and negotiate the in-game scenario relying on an instant feedback loop regarding the consequence of their actions (Arjoranta, 2011). In general, games are considered as a useful tool for creating engaging simulations of real-life scenarios, and in some cases, when the flow of the game is particularly successful, the lessons and concepts learned in the game can even extend into real life application (Crookall et al., 1987; Csikszentmihalyi, 1990). Collective Action and Hermeneutics are thus employed in the design of the game, based on other researchers successful application of them to serious games and on their connection to the current discussion surrounding quantum innovation, such as considering earth an inherently socio-technical environment and collaborating across multiple levels to govern and sustain a shared resource.

Research Methodology

This report set out to investigate what the design of a serious game that can facilitate in the transition to QS PKIs looks like. To answer this, the report relied on data collected across multiple sessions, each building upon the results of the last one. Firstly, data on the necessary requirements for the game was collected, which was then translated into design requirements. These requirements were then incorporated into a game design, which made up Prototype 1, which was tested, evaluated, and re-imagined into a new design, which became Prototype 2. This section of the report will explore these steps. First it will introduce what data was collected in what order, and then go into explaining the requirement elicitation session, then the design requirements, then Prototype 1 and its review feedback, and lastly Prototype 2.

For this report, three separate data collection sessions were conducted.

1. Firstly, a requirement elicitation session was conducted with transition stakeholders to identify relevant requirements for the game from a stakeholder perspective. Using these requirements to inform the game design in collaboration with the chosen theory.
2. Secondly, the first prototype of the game was created and tested. Prototype 1 was ultimately not successful, and the data gathered from the testing session was used to create the next prototype.
3. Lastly, Prototype 2 was created based on the feedback given by the test players of Protype 1. This version was tested similarly to the first version by players and overall did much better. A more in-depth description of the two prototypes and their successes and failures can be found in Table 3.

Below, the report will first outline the requirements elicitation session and its results. Then it will go into the design requirements that were developed from requirement elicitation. Lastly, this section will look at the two prototypes created and how they fulfilled the design requirements.

Requirement Elicitation

In the initial stage of development, the process focused on identifying requirements for the game that were considered relevant by the stakeholders in the field. Since the game is intended to have real-world impact, it was crucial to ensure stakeholder involvement throughout the process. One of the challenges that arise from this approach to design development, is that this combination of topics is still relative new, which means there is a limited supply of experts. For the requirement elicitation, we defined an 'expert' across four characteristics: knowledge of PKIs, Awareness of the 'Quantum Threat', representative of the PKIs sector, and experienced in implementing and integrating new technologies and facilitating change in organizations. This group of experts were presented with a list of over forty proposed requirements presented in the form of a statement and were asked to rank them on a scale of one to five, with one being 'Fully Disagree' and five being 'Fully Agree'. In addition to this, the experts were asked to explain their ranking of each proposed requirements, by attaching a few words via post-it. This was used to contextualize the rankings and gain an overview of the opinions and motivations of the experts in the field, as well as what was commonly agreed upon and what topics were more contentious. This is reflected in Table 1, where twelve requirement are presented which were chosen from the elicitation session. The first five requirements are the requirements most commonly agreed upon by the experts, and therefore also have the highest ranking. Requirements six through nine show the most debated requirements, where the experts where most split in their opinions. Lastly, requirements ten through twelve show the requirements that most experts disagreed with. The full extent of this part of the study can be found in the publication by Christiansen et al. (2023). The final list of requirements selected from the process, can be found in Table 1.

NUMBER (#)	REQUIREMENT FORMULATION	AVERAGE SCORE (1-5)
#1	The game shuld be (re)playable for multiple phases in the transition process	4
#2	After the game, the players should leave with at least one clear goal to implement in their organization	4
#3	The game should help players decide on what to do with NIST PQC standards	4
#4	The game should expose the interdependecies organizations have when it comes to migrating to QS PKI	4
#5	The game should focus on positive scenarious: How we can use collective action to avoid the quantum threat	4
#6	The game should focus on individual sectors	3
#7	The game should help players determine an effective governance structure towards QS PKI	3
#8	The form of the game should encourage interaction between players	3
#9	The players should have a basic understanding of PKI and the quantum threat	3
#10	The governance structure should be focused on a specific sector to be effective	2
#11	The game should determine a feasible PQC roadmap for the sector	2
#12	Before the game, the player should have at least one idea of what to achieve with the game	2

Table 1. Final requirements from requirement elicitation session (Christiansen et al., 2023)

Design Requirements

After finishing the requirement elicitation process, their contents were abstracted and formulated into design requirements. This was done by combining the expert input with recommendations lifted from literature on applied collective action research in the fields of cybersecurity, serious gaming, and socio-technical transformations to identify transition pressure points for QS PKIs (Christiansen et al., 2023). The pressure points could be condensed down to the following:

1) Create collective awareness amongst actors
2) Emphasizing the role and relevancy of interoperability in the transition
3) Prioritize increasing knowledge-sharing between actors
4) Employ real-life use cases to bridge the gap between idea and reality (Christiansen et al., 2023).

The list of requirements lifted from the elicitation process was then combined with the transition pressure points and utilized to create and formulate design requirements for the game. In Table 2 you will find the design requirements and their descriptions.

Design requirement	**Description**
Knowledge-sharing:	The game will facilitate knowledge-sharing through guided in-game conversation
Meeting space:	The game will fulfill the role of physical meeting space between users as a practical implementation of a communication mechanism
Interaction:	The game will facilitate interactivity between players as a way to lower the bar for initiating communication between actors.
Increased comprehension:	The game will deepen the players understanding of the technological, organizational, transitional, and collaborative elements of the transition.
Neutral ground:	The game will be a neutral 'community' meeting space that users can use for conflict resolution.
Awareness:	The game will create awareness for the users about their own knowledge gaps
Next steps:	The game will, by the end, have players produce a detailed description of their next steps

Table 2. Design Requirements

Prototype 1 and 2

The design requirements in Table 2 were translated into two game designs. First, they were interpreted upon and implemented in the design for Prototype 1. A first prototype is commonly designed with the intention to be further developed or even fully redesigned at the next step of the process. This is because the first prototype is the first attempt at instantiating the game and the first opportunity to test whether or not your inputs and mechanisms in the game are being interpreted as intended (Meijer, 2009). We assessed this by utilizing the player output from the game testing session through various means such as observational data and survey data, and use this information for further development of the game. For testing both of the prototypes, observational data was being collected during the session and surveys were filled out before and after the game, asking the players to self-assess their knowledge on specific topics and estimate whether the game had impacted them. Prototype 1 relied on what can be referred to as a 'value-trade structure' and Prototype 2 relied more on a 'time-urgency structure'. Prototype 1 relied on the player's willingness to trade and develop through collaboration with their co-players, by selling and buying skills and services that were needed in the transition in order to ensure the sustained well-being of their group. This design was highly complex, with many floating components and two different point systems. Prototype 2 used the element of time to highlight the urgency factor of the transition, and to showcase that the 'Quantum Threat' will continue to develop even if our transition capabilities do not. This design had a less complex design with fewer floating components, and one centralized point system.

The design requirements were used as a mechanism to assess the success of the individual design. In principle, the game needed to fulfill all of the design requirements in order to be considered successful. The output data sourced from the game sessions was used to assess whether or not the game had achieved this. However, it was considered unlikely that the first prototype would fulfil all of the requirements seeing as it was solely build on inferences which had been drawn from literature and contextual input from experts. It was expected for the second prototype to fare better than the first. With this in mind, a mechanism of relativity was implemented, wherein if the design could fulfil five out of the seven requirements, it would be considered relevant enough for further prototype development. As can be seen in Table 3, Prototype 1 only succeeded in fulfilling one of the requirements, which meant that it was not considered relevant for further development. Instead, the feedback given by the players and the output data gathered in the session was utilized to build a new prototype, namely Prototype 2.

Design Requirements	Rating in **Prototype 1**	Principle	Rating in **Prototype 2**
Meeting space	-	Meeting space	+
Knowledge sharing	-	Knowledge sharing	+
Interaction		Interaction	+
Deepening understanding	-	Deepening understanding	+
Neutral ground	+	Neutral ground	+
Awareness	-	Awareness	+
Next steps	-	Next steps	-

Table 3. Success ratings for Prototypes 1 & 2

Based on the feedback supplied by the players, as well as the output data gathered, we were able to compile a list of reasons Prototype 1 did not succeed and lessons that could be learned from it.

1) **The game did not succeed in creating a shared physical space and thus did not succeed as a communication mechanism either.** The game lacked a practical, physical representation of a shared space, like a piece of paper to fill out together within the group. As it was, the game did not manage to achieve a shared space and did not invent reason for communication between players, even though they all were physically present.
2) **Less/no individual papers.** In Prototype 1, the players filled out, referred to, and traded individual pieces of paper. However, according to the players, this was too separating and hindered open communication between players. It made the game seem more individually competitive than as a group activity.
3) **Remove the non-participating observer from the table**. The players should be able to play the game independently. Having the game developer at the table monitoring them often resulted in them continuously referring back to the developer for every action and discussion, instead of discussing between each other, which ruined the immersive experience. In short, instead of talking to the other players at the table, they would only address the developer as

they were seen as the 'leading authority' at the table, which created an accidental hierarchy in an otherwise egalitarian game.

4) **The game lacked urgency,** such as visual/tangible representation of an "enemy." According to the players, the game lacked a motivational element of something to achieve or something to beat.
5) **The many rules and mechanics of the game were too confusing and restricting.** The rule system for this game was very complex and operated on three different levels and was too difficult and complex for a one-hour game.

In the end, the game only managed to function as a neutral meeting ground and failed at all other requirements. Therefore this design was considered to be unsuccessful as a relevant prototype for the HAPKIDO project, but the feedback given was used in the development of Prototype 2.

For Prototype 2, it can be seen in Table 3 that this prototype was much more successful in meeting the requirements according to the test players. While it was largely successful, it did not fully succeed in addressing the next steps for the players, which is one of the most important requirements to address. Relying on feedback from players and the output data sourced from the test session, we were able to create a list of three elements that could be improved upon in future prototype developments.

1) **The game lacked a narrative structure,** which disrupted the flow and ultimately minimized the impact on understanding and knowledge sharing. While both principles were still achieved, they *could have been more successful.* Additionally, the compromised impact of comprehension and knowledge-sharing also meant they lacked some of the necessary insight to visualize their next steps.
2) **The game operated from a macro-level perspective.** The players reported that a top-down, macro-level perspective negatively impacted their understanding of the details regarding transition complexity, and therefore lowered their overall awareness and understanding of what their next steps should be. While the game still achieved awareness, it failed to get the players to understand what their next steps should be, as established above. Feedback from players indicates that this could have been mitigated with more specific examples in the game, to make the tasks and interaction more realistic.
3) **Knowledge sharing was achieved, but the impact was lowered by player arguments.** It happened that players disagreed on more 'contentious' terminology. This was despite the game supplying working definitions to avoid situations like these. Even though this slowed down

the process of the game, which was undesirable, it was representative of a the real-world transition, as experts frequently tend to disagree on details like terminology. This is especially true for a field such as the transition to QS PKI or the field of post-quantum cryptography, as many of the details are still being decided and developed, thus leaving a lot of room for debate.

Ultimately, Prototype 2 was considered a success and with the feedback in mind, it is believed that the game can achieve the 'Next Steps' requirement as well.

Theory

The theories underlying this game design are collective action and hermeneutical theory. In this section the report will guide you through a brief description of the theories, their context to the topics of this report, and how they were applied in the design of the game. Firstly the report will look at collective action theory and then subsequently hermeneutical theory.

Collective Action Theory

As mentioned previously in the background portion of this report, Collective Action (CA) is a theory which pertains to the sustainability and behavioral traits surrounding resources which are shared between a group. Within the framework of this report and the design it presents, the shared resource is considered to be PKIs as a whole, despite the production and development of the technology being somewhat fragmented, the resource that is gleaned from PKIs is measured as a single element. Within Ostrom's (2009) CA framework, there are eight Design Principles for managing a shared resource within a system that function as core elements to the theory. To the best of the authors' knowledge, these principles have yet to be defined clearly in relation to the transition to QS PKIs. For the time being, it has been possible to indicate which principles need further contextualization and interpretation in order for them to be possible to instantiate in the transition and future research will need to be dedicated to this purpose. A comprehensive overview and description of the principles can be found in Table 4.

For the development of the game design, Ostrom's principles were used to inform our understanding of collaborative social systems, and they were used as a guide post already from the first step of the process when formulating the statements for the requirement elicitation session. From there on, a condensed list of key take-aways from literature on CA applied to cybersecurity, serious gaming, and socio-technical transformations allowed for us to be able to identify transition pressure points when combined with the expert input. It was these pressure points that, when combined with the initial requirements lifted from the expert session, made it possible to create the Design Requirements for the game. Thus CA and especially Ostrom's principles has been central to our understanding of human interaction in the game and what qualities should be fostered between the players.

Principle	Description
Clearly defined boundaries	Clear definitions of who is allowed to use what and how much, makes it easier for the community members to utilize the shared resource. This also helps the community clearly distinguish who is inside and outside the system, and so therefore who must provide maintenance of the system and who also receives the benefits from it.
Proportional equivalence (of cost and benefit):	The ones who receive the highest benefit from the resource are also the ones required to pay the highest cost for maintenance. E.g., if someone has better tools for extracting natural resources and therefore are extracting more, they should also be paying more for maintaining the resource.
Participation	Those who are affected by the rules set in place for the system should also generally have a say in making the rules. Generally those actually using the system will have a better idea of what rules will actually work for them.
Monitoring (of activities)	To actively monitor the physical conditions and irregular behaviours within the system, to assure that the rules are being followed. Managing the resource is done better when all parties have access to current and accurate information about the use of the resource. It is important the monitors of the system are accountable to the users of the system or are users themselves
Graduated sanctions	Scaled punishments or consequences for "free-riders", so people who are using the resource but not contributing back or who are not respecting the rules of the system by overusing. These people will experience sanctions/consequences from other users in the system or the officials who are accountable to the users. The first sanctions will start very low for first time offenders and then increase if the offences continue to occur.

Conflict resolution	Users of the resources must have access to low-cost, easily accessible arenas to solve conflicts between users. Moreover, the conflicts needs to be able to be solved relatively quickly by use of the arena. This mechanism will allow the users to determine what is and isn't a rule and which actions that are permitted and which are not. This also keeps the ecosystem of the rules and principles for the resource current and developing.
Recognition of rights	The users/ community members have the right to set up their own institutions and this right is not challenged by external bodies like international governments, etc. It is important that community rights are recognized, as it also functions as a strengthening mechanism that hinders outside entities to come in and use or pollute the resource.
Nested enterprises	Long lasting resource systems are typically large and complex as they have developed and grown over the many years/generations of its existence. Therefore they are commonly also divided into multiple tiers of nested organizations which represent the different layers of the systems, such as the users, locals, national and international perspectives. This means that different levels pertains to different aspects of managing the resource in the system, such as provision, monitoring, enforcement, conflict resolution, and governance elements.

Table 4. CA Design Principles (Hess & Ostrom, 2007; Ostrom, 2009, 2015)

In terms of identifying the principles in need of further contextualization and interpretation in the transition, an example could be proportional equivalence, which currently is met with a lack of established accordance between the cost and benefit of the transition to QS PKIs. Organizations are becoming increasingly aware that they will have to migrate to a QS PKIs in the future, but it remains unclear how much it will cost, what the various types of cost will be, and what exactly it will mean to be sufficiently 'quantum safe'. Likewise, there is no clear definition of the boundaries between users and resources, procedures for rule-making, and graduated sanctions. Despite these unclear areas, previous research shows us that CA is a relevant theory to apply to socio-technical research (Gillard et al., 2022; Shackelford, 2016, 2020; Whyte, 2018). Over the past years more and more researchers have started extending collective action into socio-technical and digital spaces, and doing so by reassessing key terminology and estimating how it can be applied in these new digital spheres. For example, a key term in CA is 'the commons' which typically refers to the physical resource being shared by the actor system. When it comes to digital infrastructures, researchers argue that we can understand 'the commons' as not a physical space or physical wealth of shared goods but rather as the "shared global infrastructure" (Shackelford, 2016; Shackelford, 2020). Technologies such as PKIs which have been deployed globally and often connect users and services across country borders can arguably be considered a "shared global infrastructure". What makes PKIs such a versatile technology is the opportunity for individualization, as there are many different options and solutions offered, which makes it highly customizable but also fragmented in the sense that we do not have one main provider of the technology, but instead many. Despite this, within the game and within the perspective of CA, PKIs as a technology is considered as a whole shared resource relied on by the system. In the case of PKIs, the resource is being relied on across many countries, thus making it a shared global infrastructure. Furthermore, collective action is also considered an ideal method for targeting latency issues in cybersecurity and well-suited for tackling time-sensitive risks (Gillard et al., 2022). In summation, applying CA to the Dutch transition to QS PKIs is a well-suited next step for extending the theory and will also provide an explorative scientific contribution to the continued development of the theory. This research will provide more insight into what can be expected when extending CA into socio-technical spaces, which in turn will provide further empiric contributions to explore the epistemological and ontological trappings of constructing knowledge around cybersecurity governance and its ability to extent this into real-world impact, which thus far has had limited contributions (Whyte, 2018).

Hermeneutical Theory

In the larger design of the game, we relied on hermeneutical theory to understand how we could structure, approach, and present a game that needed to be able to teach its players a large quantity of knowledge in a relatively short timeframe. To do so we leaned on hermeneutical theory and two concepts from it; the hermeneutical spiral and real-time hermeneutics. The hermeneutical spiral refers to the learning process wherein the student is introduced to the 'big picture' view of a subject, and then introduced to smaller, more detailed part of it, then re-introduced to the 'big picture' with a new understanding of its complexity. After this the student is then once more introduced to a new part, to help them see more nuance in the 'big picture', and so the circle continues (Suchting, 1995). Real-time hermeneutics is about creating a shared reality between the players, that relies on a constant and instant feedback loop which divides their actions in a dichotomy of either positive or negative responses, such as right or wrong (Arjoranta, 2011). Through this, the game should be able to create a micro cosmos simulating reality, and through the flow of the game the players should be able to simulate the transition so well that they are able to translate the knowledge into the real world (Crookall et al., 1987; Csikszentmihalyi, 1990). When pairing hermeneutics with the three main goals of the game (awareness, comprehension, collaboration), we were able to arrive at three design principles to steer the design of the game, namely *learning perspective, learning approach,* and *learning content.*

Learning perspective pertains to how we could apply the concepts of real-time hermeneutics and the hermeneutical circle in the game, both holistically and within the individual levels to make sure that the game was optimally primed to assist the players in comprehending a complex new topic. This principle was chosen to target comprehension as a goal, as that type of in-depth learning cannot not just happen as a result of the topics discussed or how they are approached. It has to be prioritized on a fundamental level, so that every mechanism of the game leads back to a larger point of learning. As such, the game is not just a compilation of lessons to be learned, but one carefully woven and designed tapestry with many parts that all come together to form the big picture. The *learning approach* pertains to how we could implement the hermeneutical circle in the game and it did so in relation to the order of the levels. The levels were stacked based on what was estimated to be the most fundamental and 'big picture' knowledge which was used as the first level and then the game alternated between the 'parts' and the 'big picture'. As such, level one and three constitute the 'big picture' and level two and four are 'the parts'. The 'big picture' takes a macro level perspective and 'the parts' takes a micro and meso perspective. By employing this structure and alternating between the perspectives the game aims to impact the awareness of the players by providing more nuance and complexity with each level. *Learning content* pertain to utilizing the structure of the hermeneutical circle to approach the game's content. Within the concept of the hermeneutical circle, in order to ascertain what makes 'the whole', i.e., the 'big picture', one must first ascertain what 'the parts' are. Once this has been done you can approach assembling the big picture. This was the role of the *learning content* principle, to decide what scenario-specific examples needed to be discussed in the game. Moreover, they all needed to be cohesive and be able to stimulate the flow of the game in order to enhance the reality of the simulation to the degree to which it can move beyond in-game understanding to real-life application. As such, this principle was made to target collaboration, which as a goal more broadly looks at extending the knowledge beyond the game by enabling the players to be able to identify real-world collaborators, risks, urgency level, and next steps. To decide on the examples used in the game, we had the expert-identified transition pressure points to guide us, namely, collective awareness, interoperability, knowledge-sharing, and real-life use cases (Christiansen et al., 2023) and input from experts within the fields post-quantum cryptography, governance, and PKI.

Walkthrough of the design of Prototype 2

The section below constitutes the introductory part of the game, namely the description. What is described below is already covered in the verbal introduction given prior to the start of the game, but for the ease and comfort of the players, it is reiterated once more in a written format.

Description:

You are: *The Coalition of the Willing*, a centralized decision making authority in your country. You each sit on the council as a representative from of the larger banks in your country. You act as a centralized banking authority that has the authority to make development and policy decisions for the whole sector. You are independent from the government, however your nation state is a part of a larger international collaborative effort (similar to the EU). You still have to adhere to the regulations of this international collaborative effort, or they have authority to penalize the banks in your country.

Objective: You have agreed to have the Coalition lead the transition to quantum safety for the banking sector in your country. This means you will have to now make a series of large-scale decisions on behalf of the banks in your country considering the greater good of everyone involved.

Scenario:

A large bank in a neighboring country has been attacked. Banks in your country possess similar security infrastructures and likewise have large quantities of sensitive data, which correctly leads you to worry you might be next. **Time is of the essence as you do not know when the attack will be.**

If your banks were compromised, the implications would be massive, including but not limited to

- Sensitive data stolen
- Personal data stolen
- Long-term infrastructures damaged
- Physical services like ATMs would be inoperable
- Digital services like online banking rendered inoperable

People would no longer be able to do basic things like get groceries or pay for their public transportation. Without commonplace access to the banks and the services they provide, your country would enter a standstill, severely impacting the lives of the citizens and negatively impacting your national economy.

Keep in mind your country has a similar structure to the Netherlands, meaning the banking sector has a centralized governing body like the *NVB*, which controls the collective moves of all the banks.

For example, when contactless payments became more and more commonplace in the Netherlands, the decision was made to make this feature available in all ATMs as well. This meant a huge standardized effort to replace all the ATMs within the same timeframe. The NVB established the relevant standards, hardware choices, and software choices, leaving the banks to make their own arrangements within a deadline. In the end, all 5200 ATMs in the Netherlands were exchanged and updated within a two-week period.

Level 1

Similar to the other levels, Level 1 has one main task worth 10 points and then one shorter optional task worth 3 points. The purpose of the main task is to help the players get a general overview of their topic, while also engaging with the actor complexity inherent to it. The extra prompt urges the players to attempt to define the actors relevant to the case. This allows them to draw on the reflection from the previous main task, and actively take hold of that knowledge by analyzing it and defining it in a meaningful way. The purpose of this was for the players to retain the information they learned from each other in this level, but also go a step beyond merely retaining the information and finding meaning in it according to their own knowledge background.

Timeframe: 10 minutes

Level 1 Assignment: Services (10p)

At this level you will choose services. By services, the game refers to the services offered by banks to costumers, such as cashless payments, online banking, ATMs, cash withdrawals, loans, online transfer of funds internally and externally to the bank, and so forth.
At this level, please choose which services and how many to secure, with the imminent quantum threat in mind:

- Attempt to secure one to two services fully

Or

- Attempt to secure all services as much as possible (no services will be fully secure)

You can either endeavor to secure 1 to 2 services fully or all of them a little.
It will not be feasible to secure them all in the time frame.
Consider the cost/benefit of services. For example, you can choose to prioritize securing digital banking and cashless payment (i.e., credit/debit cards). These would make it possible for the majority of society to still function after an attack. But then, what about elderly citizens who often rely on cash withdrawn from ATMs? If they cannot withdraw cash will they be able to have their basic needs met?

Level 1.5: Extra prompt: Define Participants (3p)

You are leading by example, meaning that others will follow in your footsteps.
Therefore, you must consider who you are trying to include in the transition with the precedents you are setting and how you envision people to follow your guidelines.

Tip: There are different ways you can distinguish between participants. There is no right or wrong answers, so feel free to interpret the questions in a way they resonates with you.

- One example is the PQC handbook's categories of regular adopters, urgent adopters, and cryptography experts.
- Others suggests the lenses of Followers and Developers, Directly affected and Indirectly affected.
- Likewise, you could also consider a socio-technical lens, such as users, vendors, developers, regulating bodies, etc.

Attempt to answer the following:

- Who is this transition for?
- What are the different types of participants?
- Who is contributing what?
- What do you (as leaders) need from the different participants?

Level 2

This level asks for the players to delve deeper into complexities of actors and actor roles in the transition. Relying on what they identified in the previous level, they will first choose hardware and software providers for their services, and then they will take a critical look at how we the transition participants can be organized/nested according to their own structure. The purpose of the extra prompt here is to have the players engage with the actor complexity through a similar approach to the hermeneutic spiral. While they in the last level had a chance to dive deeper into the complex knowledge actor, for this level they will take a step back and attempt to organize this knowledge according to the levels within the field that make sense to them.

Timeframe: 10 minutes

Level 2: Hard-&Software (10p)

Based on the decisions you made in the previous level, you have to decide what hard- and software you are investing in for your chosen services.
It might be necessary to update your hard and software to ensure compatibility with new updates and maintaining the security of the given service. You might also find in your group that it won't be the case. **There are no wrong answers.**

Tip: These products can for example be hardware for card payment terminals and ATMs, as well as software for security elements for online banking like PKI systems.

Please consider:

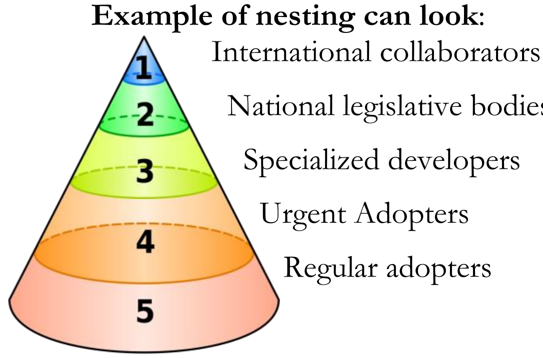
- What qualities and requirements are necessary for your new services in relation to the quantum threat?
- Are you choosing fully new hardware and software?
- Will you wait a little longer for your current service to develop a PQC update?
- Which hard- and software are you choosing?
- How will you implement the new hard- and software?

Level 2.5: Nesting participants (3p)

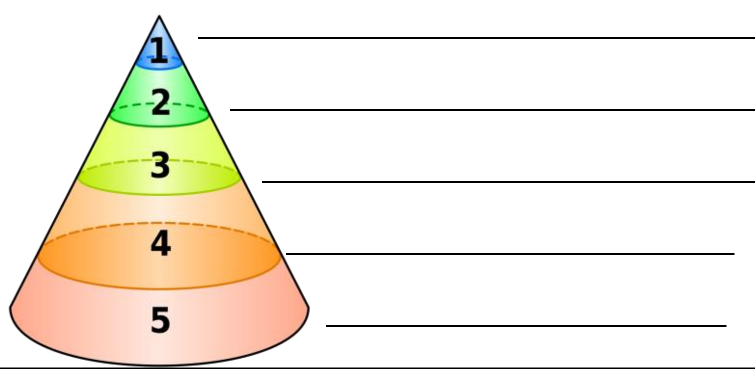
One way to recognize the different needs of actors is to nest the system, meaning to create levels within the system. However, it is very important to recognize the levels in the system and recognize their authority to make decisions.
Tip: This can also be considered through the lens you explored in prompt 1.5. Relying on the same categories of participants, you now have to evaluate which would be considered closer to a 'ground level' and who would be closer to a 'top level'
Please consider:

- What can the different levels in the system look like?
- What can they be recognized as? (e.g., enterprises, actor types, needs, contributions, etc)
- How can the levels' voices be heard within the system?
    - (e.g., should there be a council where each level has a representative? Should there be hosted plenary spaces where any member of the system can show up and be heard? Should it be another solution?)
    -

Example of nesting can look:



Fill in yourself:



Level 3

This level explores the role of outside authorities on the transition through the topic of technological standards. Presenting a hypothetical timeline for the players to work with this level presents them with the task of choosing which technological standard to implement according to a specific type of technology. The extra prompt continues to follow the hermeneutic spiral and again moves back into the complexity of the issue by having the players discuss the limitations of what an actor is.

Timeframe: 10 minutes

Level 3: Standards (10p)

Technological standards are the lifeblood of sustainable digital innovation. Without a cohesive approach to digital development, there would be no interoperability between different services.
For example, if there weren't universal standards for PKI systems (safe data communication), your browser would not be able to access Google, or you would not be able to transfer money across different banks. The internet is entirely reliant on the interoperability that is provided by the standardized approach to shared cybersecurity mechanisms, like PKI systems.
The standards for technologies such as these are developed by organizations like the National Institute of Standards and Technology (NIST) and Internet Engineering Task Force (IETF). The standards developed by these organizations are anticipated and implemented by users all over the world. New PQC standards are currently being developed by NIST, but the exact release date is unknown. They estimate the release to be around 2024.

Tip: For the transition to quantum safety, there are three types of relevant standards being developed to ensure the on-going safety of participants:

1. **Post-Quantum Cryptography** (PQC, New type of cryptography able to withstand quantum computer attacks)
2. **Quantum Cryptography** (QC, cryptography written on and for a quantum computer)
3. **Hybrid Cryptography** (HC, incorporates elements of both quantum and post-quantum cryptography with the idea that it will create more durable and agile cryptography)

The timeline for the release of new standards is approximate:
2024: PQC → 2027: HC → QC: 2035(earliest)

Please consider:

- **Which variation do you choose?**
- **Which standard do you choose?***
- **Contingency plan?**

* (Existing or new standard? Existing means immediate implementation and thus faster security, but it might not be interoperable with future standards, meaning you will have to change later on, which can be very costly.

However, waiting for new standards to be released puts you at risk as you are less secure, and if it turns out you are defying EU regulation and data protection laws, you will be fined 4% of your banks' annual profit, approx. 800.000€)

Level 3.5: Extra prompt: Recognition of rights (3p)

Different transition participants might choose differently for standards; some would like to wait, and others choose to rely on preliminary standards. This would be within their rights to choose based on their individual needs.
The transition to quantum safety, even within the bank sector, is a huge and complex process. It pertains to a multitude of participants and every single one of them has a unique set of needs.
To ensure a coherent and agile transition, it might be relevant to give various actor levels a way to have their concerns and issues addressed. How will you do this?
Tip: Consider what the modus for such mechanism would be – would the council itself be the ones to address the issues or would it be better to have a separate, independent space for this?

- What mechanisms do you put in place to ensure that these rights can be recognized in the system?
- Where does this mechanism exist?
- How does it function?
- Who serves on it?

Level 4

In this level the players engage with a meso governance perspective of the transition, by discussing interoperability. Interoperability is key for the transition and is therefore also one of the most difficult topics to solve. Herein the players a tasked with discussing interoperability from a meso governance perspective and how exactly the problems inherent to interoperability can be solved, handled, and mitigated. The extra prompt seeks to combine all the information from the prior three prompts, and encourages the players to consider the monitoring and sanctions of a system. Firstly it encourages them to even consider if these elements are necessary for this transition, and if they are, what should such mechanisms look like?

Timeframe: 10 minutes

Level 4: Interoperability (10p)

As discussed in previous levels, it is absolutely paramount that there is interoperability between services and users. It ensures there can be continued flow of data and communication between banks that is safe from malevolent interference.
Without interoperability many of our core functions would not be possible, like communications between systems, as well as backward compatibility with older versions of certain systems and services.

Please consider:

- How are you ensuring interoperability for participants in the transition?
- Between the systems and services?
- How are you communicating this?
- How do you ensure your guidelines are followed?

Level 4.5: Monitoring and Sanctions (3p)

One way to ensure that the transition is successful is to ensure absolute interoperability. This will be in the best interest of all users. Still, sometimes users need extra incentive to follow the provided guidelines, both to ensure the timeframe of the transition as well as the quality of the implemented solutions.
Including mechanisms that provide monitoring and sanctions might be beneficial to ensure compliance within the transition.

Tip: Consider what this might look like. Would it be an outright penalty, like a monetary fine for a rule broken? Would the sanction maybe be softer and occur as a natural consequence of not following the suggestions provided? Also, how will you keep an eye on the transition and its progress? Is it even necessary to do that? If yes, who would monitor it? A centralized governing body like the Coalition or an independent entity?

Please consider:

- How will you ensure that the transition is followed through as intended?
- Will you monitor the progress of the transition?
    - If yes, who will monitor it?
- What will you do if someone does not transition or does not follow the guidelines provided for a successful transition, thus compromising the collective safety of all the users in your country?
- Will it be necessary to employ sanctions or other mechanisms to ensure compliance?
    - If yes, what would they look like?
    - If not, why not?

Conclusions and recommendations for further research

The main objective of this report was to explore what the design of a serious game that can facilitate in the transition to quantum-safe PKIs looks like, while simultaneously explore the sub-question of what the theoretical contribution of the game would look like. To explore the element of the game's theoretical contribution first, the design of the game is informed by two theories, namely collective action and hermeneutics. These both contribute key elements, which were used in approaching key actors and receiving expert input on the game to further the design and ensure it remained relevant for real-world impact. The theoretical contribution of this game mainly pertains to collective action, as this game contributes to extending the theory onto a new frontier. Some research has already been done establishing the relevancy of the utilizing collective action theory in these spaces, however, we need to continue extending the theory into this space as some researchers have discovered idiosyncrasies in the behavior of the theory when applied to socio-technical spaces which means the theory needs to be rediscovered in a socio-technical context and its application to new scenarios mapped and recorded, which this report in part aims to contribute to. Moreover, the ontological and epistemological nuances of collective action in a cybersecurity perspective still require further development and mapping through empiric data, which this game likewise contribute to.

The main purpose of this report was exploring what a design of a serious game that could facilitate in the transition to QS PKIs looked like. The main conclusions for this purpose can be found in the seven design requirements that is estimated to be capable of creating the necessary awareness, comprehension, and collaboration skills amongst the players. These design requirements are 1) meeting space, 2) knowledge sharing, 3) Interaction, 4) deepening understanding, 5) neutral ground, 6) awareness, and 7) next steps. For the design to be considered eligible, it needed to fulfill five or more requirements and only Prototype 2 achieved this. The only requirement Prototype 2 did not fulfil was 7) Next Steps, which indicate an issue with extending the knowledge of the game into a real-world understanding. One reason for this can be concluded as issues with the simulation of the game and with the flow of the experience, meaning that the experience and meaning derived from the process is impaired due to this. The intention for the quality of the immersive, simulation experience and the game flow was to accurately depict situations that could be found in a real transition to QS PKIs and how the players deal with them and develop realistic solutions to the problems. Ideally, this should have been done in such a way in the game that the knowledge gathered from this process should be translatable into real-life for the players, however players reported some difficulties in the experience, like finding the game too macro level in it its approach. Likewise, they thought the game would benefit from a more narrative structure, which would improve the immersive experience and the knowledge gleaned from it. Since it is currently not, we suggest future research be dedicated to solving the difficulties presented by this gap between game and real life. Based on the knowledge we have from testing the game, we suggest that the first step to addressing these difficulties are by targeting the quality of the game simulation and the flow of the game. This can for example be addressed through simplifying the scenarios presented, reducing the complexity of the game system itself, or moving the game from the macro level to a meso level instead. Overall, Prototype 2 was successful as it fulfilled six out of seven design requirements, which means it is fit for further development, with special focus on addressing the difficulties within the design requirement 7) Next Steps.

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