The application of activity theory to explain collaborative technology use in healthcare: The case of a chemotherapy ordering system

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Abstract

Today cancer is one of the leading causes of death. Treating cancer requires the administration of chemotherapy; however, this is a complex and complicated process which requires the collaboration of many individuals. In many hospitals hand-based systems are used which can also cause further problems especially with regard to errors. This study focuses on the implementation of a computerised chemotherapy system. Further, based on Activity Theory the chemotherapy administration process is framed as an activity system so that contradictions can be uncovered. In doing so, the study proffers activity theory as a robust and rich lens in which to analyse all the critical success aspects of the implementation process so that a successful assimilation of the solution into practice may ensue.

1. Introduction

Due to increasing digitalisation, numerous processes can be optimised by saving time, reducing error rates and most important analysing, evaluating, and creating knowledge of the collected data. In healthcare these opportunities are now being recognized especially in light of the challenges of access, quality and value facing healthcare delivery in all OECD countries [1].

One area of clinical care that can benefit from digitising is in cancer care, given the many and varied processes involved. We focus on a specific private hospital in Australia which is introducing a computerised solution to manage the whole oncology treatment process of a patient from initial diagnosis through to post treatment follow-up as an exemplar case study. In this hospital, 20% of the patients are treated for cancer which makes cancer services a key clinical area. To date, a major aspect of cancer treatment is the administration of chemotherapy. This is considered a complex task especially given that numerous staff are involved coupled with the intrinsic toxicity of the medication as well as its generally low margin of safety [2]. It is recognized that the use of handwritten based systems for chemotherapy ordering creates certain risks whereas it is assumed that with a computerised physician order entry system the quality, safety and efficiency for the process of ordering, make-up, and administration of cytotoxic drugs can be improved [2].

2. Background

In Australia, there are public and private hospitals. Public hospitals are owned and managed by the state and territory governments. In contrast, private hospitals are owned and managed by either for-profit or not-for-profit private organisations [3]. Approximately two thirds of patients in Australia are treated in a private hospital [4]. When examining the processes in a private hospital, it is important to consider the structure of the hospital environment because this might be very different from the public sector. In the hospital examined in this study, independent consultants that are not considered salaried full-time staff are working in separate private practices [2]. This indicates that these independent consultants are free to move their patients to another hospital if they consider it as necessary. Therefore, when implementing a new computerised system into a private hospital environment, it is essential that the users are convinced and satisfied by the system. Hence, an appropriate implementation strategy needs to be developed by especially taking social factors into consideration. In addition, the implementation of new software in a running business environment needs to be planned carefully so that no or only few business disruptions occur.

In order to include the human factor into information systems the Human Computer Interaction (HCI) theory is often used because it involves the study, planning, design and uses of the interfaces between people and computers [5]. In research, we
note that it is recognized that HCI might be limited. The use of computers in social, organisational, and political contexts cannot be studied sufficiently because the relationship to the user’s goals, plans and values cannot be analysed [6].

For these reasons we proffer Activity Theory as an appropriately rich and robust lens to analyse the process of chemotherapy administration. The activity system of the process will be developed in order to find contradictions that lead to failures and disruptions. Based on that, a much richer picture of the requirements for implementing a computerised physician order entry system for the chemotherapy administration process can be created.

2. Activity Theory

2.1. Evolution of Activity Theory

In the evolution of Activity Theory it can be distinguished between three generations. The first generation is the cultural-historical theory of activity which was developed by Russian psychologists in the 1920s and 1930s. Lev Vygotsky and his colleagues formulated the basic concept which is demonstrating that “the relationship between human agent and objects of environment is mediated by cultural means, tools, and signs.” This concept of artefact-mediated and object-oriented action can be seen in Figure 1 [7].

However, we note that mediation with other human beings is not described by this model and therefore the societal and collaborative nature of actions cannot be fully represented [8].

Figure 1: Cultural-historical Activity Theory of Vygotsky (adapted from [7])

The second generation of Activity Theory mainly was driven by the work of Leontiev [7]. In order to enable mediation by other human beings and social relations Leontiev expanded the Activity Theory with differentiating between an individual action and collective activity. He developed a Three-layer-model of activity which can be seen in Figure 2. The lower levels are driven by conditions or goals whereas the highest level, the activity, is driven by an object-related motive [8].

Figure 2: Three-layer-model of activity (adapted from [9])

However, Leontiev didn’t introduce a conceptual model of collective activity. Thus, the Finnish educational researcher Yrjö Engeström extended the original concept of activity to the case of collective activity. As a first step, Engeström added the element of “community” to the foregoing notion of subject-object interaction in order to enable a three-way interaction between subject, object, and community. Second, a special type of means for mediation for each possible interaction between these three elements was defined. As already considered by Leontiev, tools and instruments are means for the subject-object interaction. Rules were introduced to mediate the subject-community interaction. The community-object interaction is mediated by division of labour [9]. The expanded activity system by Engeström can be seen in Figure 3. According to Engeström and Mwanza these mediators “[.] represent the nature of relationships that exist within and between participants of an activity in a given community of practices” [10 p.2]. Activity participants are defined as subjects that are interacting with objects to achieve desired outcomes [10]. The outcome is a transformation of the object produced by the activity into the intended result [9]. Furthermore, the projection from the object to the outcome functions as the motive of activity [8]. In Activity Theory it needs to be differentiated between object and objective. The object is either material or mental and can be modified by a subject according to the activities goal. This is why some researchers suggest extending the Activity Theory model by a goal [11].

The objects of the activity “making a driver’s license” are the driver’s abilities of driving such as parking or considering traffic rules. The objective of the subject (or driver) is to improve the abilities of driving in order to get a driver’s license. The outcome of the activity are the benefits of holding a driver’s license such as having a higher flexibility in daily life or fulfilling a job requirement. The transformation between object and outcome functions as the motive of
activity that motivates the subject to execute the activity. In essence: “If I improve my driving abilities and get a driver’s license, I will have more flexibility in daily life or a higher chance of getting a certain job”.

Figure 3: Activity system model of Engeström (adapted from [10])

In the third generation, the model is expanded by at least one more activity system so that interaction between them is possible. The challenge is to understand dialogue, multiple perspectives and voices, and networks of interacting activity systems [7].

2.2. Principles of Activity Theory

The concept of activity reflects a special type of relationship between the subject and the object. This relationship is defined by two distinctive features. First, subjects have needs and must carry out activities in order to survive. Carrying out activities means to interact with objects of the world. An activity is defined as a “[…] “unit of life” of a material subject existing in the objective world.”[9 p.12]. Subjects can not only be individual humans but also animals, teams, and organisations. Second, “[…] activities and the entities they are relating (i.e., subjects and objects) mutually determine one another” [9 p.12]. Activities transform not only objects but also subjects [9].

In other words, an activity is not only influenced by the attributes of the objects but also by the attributes of subjects. In an example, Kaptelenin and Nardi are describing the solving of a math problem. They state that on the one hand, a person’s math abilities determine how the person solves math problems whereas on the other hand solving math problems is also determining the person’s math abilities. These two distinct features are emphasising the inseparability of human beings and the world [9].

Building on further literature, Kaptelenin and Nardi are summarizing five basic principles of activity theory: Object-orientedness, mediation, hierarchical structure of activity, internalisation and externalisation, and development [9].

That human activities are directed towards their objects is stated in the principle of object-orientedness [9]. As stated by Leontiev (1981), an objectless activity is impossible. “Objects motivate and direct activities, around them activities are coordinated, and in them activities are crystallized when the activities are complete.” [9 p.29]. Taking on the perspective of a subject, this means that the subject’s interactions are organised around objects. Therefore, it is important to analyse objects in order to understand individual or collective human activities. In this analysis it is important to differentiate between objects and objectives. “Objects have their “objective” meanings, determined by their relationship with other entities existing in the world (including the subject himself or herself)” [9 p.29]. The subject has to expose the objective meanings of the objects and needs to act effectively in order to meet the needs. Objectives can not only be physical but also socially or culturally [9].

The principle of mediation states that human activity is mediated by tools. These tools can be external such as a scissor or internal such as concepts or heuristics [12]. As all key distinctive features of humans such as language, society, or culture involve mediation [9], the analysis of tools is necessary to understand human functioning [8].

The principle of the hierarchical structure of activity is already illustrated in Figure 2. The top layer is represented by the activity. Depending of a certain need, the activity is oriented towards a motive. An example of such an activity is to get a driver’s license in order to be a fully functional member of society. An action in this scenario could be the enrolment in driving school. This is a conscious process that is directed towards a goal (e.g. enrolment in driving school) that must be undertaken to fulfil the object of the activity (get driver’s license). Goals can be divided into sub-goals. In some cases, it is also possible that a goal of an action is becoming a motive and therefore the action is transformed to a separate activity. The lower-level units are called operations which are implementing the actions. An example of an operation is changing lanes with a car. Operations are also called routine operations because they are executed unconsciously [9]. They are either the results of step-by-step automatisation of originally conscious actions such as changing lanes with a car, or results of “improvisation” such as instinctively acting in an emergency situation [13]. De-automatisation describes the transformation of routine operations back to conscious actions. As these complex relationships between humans motives and goals are seen as human characteristics, the three-layer model is only valid for human activities. In summary, the analysis of motivational, goal-directed, and operational aspects of human activity can be analysed based on this model [9].
The principle of internalisation and externalisation states that there are transformations between internal and external components of activity [9]. Internalisation takes place if mental processes are derived from external actions. An example of internalisation is if children stop to solve calculations by counting with their fingers. The opposite process is externalisation. Here, internal components of an activity are transformed into external components and can therefore be verified and corrected. Tools enable the process of externalisation. An example is the design of a sketch [12].

The principle of development is an object of study as well as a research strategy. As an object of study, development can be analysed at different levels, for instance, animal activity in biological evolution, emergence of specifically human forms of activity in social history, or individual development throughout various phases of life. In order to get a deep understanding of the object, development as a research strategy analyses the transformation of an object over time [13].

As all these principles are representing different aspects of human activity as a whole, “Systematic application of any of the principles often makes it necessary to eventually engage the others as well” [13].

In the literature, it is recognised that Activity Theory can be a complex framework for analysing and designing purposes. Even though it is characterised as an analytical framework, it is recognised that it does not offer ready-made techniques and procedures for research. It is considered as an evolving framework that only contains general guidelines and therefore must be further developed [14].

However, Activity Theory is regarded as a powerful lens for studying complex social systems. This statement can be underpinned by the fact that Activity Theory is focusing on the relationships that exist in an activity system. In addition, the historical development of the activity as well as the use of tools is analysed. Different user perspectives of the subjects are considered, too [14].

2.3. Contradictions in Activity Theory

Contradictions in activity systems exist because activities are constantly developing and even most-well planned actions involve failures, disruptions, and unexpected innovations [9]. By analysing the activity system, the underlying contradictions that lead to these failures, disruptions, or innovations may be recognised [8]. In Activity Theory four types or levels of contradictions can be identified [9].

First-level contradictions deal with inner contradictions of each of the components of an activity system. The components of an activity system are subject, object, community, instruments, rules, and division of labour. For example, a physician chooses a more affordable medication over the best available medication that is more expensive [9].

Second-level contradictions occur between the components of an activity system. For example, if a certain type of medical treatment is unsuitable for certain patients [9].

Third-level contradictions are “potential problems emerging in the relationship between the existing forms of an activity system and its potential, more advanced object and outcome” [9 p.35]. For example, when a new technology system is being implemented there is resistance which prevents new work process and integration of the new technology solution with the new work processes to ensue.

Fourth-level contradictions occur between different systems of activity that are involved in the production of a joint outcome. For example, a positive effect of surgery can be undermined by an improper follow-up rehabilitation [9].

2.4. Activity-Oriented Design Method

The Activity-Oriented Design Method (AODM) was developed by Mwanza and is supporting researchers to identify contradictions in activity systems [14]. According to Engeström, contradictions are seen as means of expanding and transforming the system and developing human practices. In other words, uncovering contradictions is necessary in order to improve system design [14].

In addition, design insights for further study and refinement can be generated [14]. In order to support data-gathering, analysis and communication of design insights, AODM offers four methodological tools [7]. These tools are divided into several stages and are described in Table 1.

<table>
<thead>
<tr>
<th>Stage 1 – Defining Activity System – Eight Step Model</th>
<th>The Eight Step Model puts theory into practice by interpreting the situation being examined in terms of Activity Theory based elements of the human activity system.</th>
</tr>
</thead>
<tbody>
<tr>
<td>Stage 2 – Activity Notation</td>
<td>Reduces complexity in the situation being examined by facilitating decompositions or breaking down of a complex activity system into sub-activities in order to facilitate detailed investigation.</td>
</tr>
<tr>
<td>Stage 3 – Research Questions</td>
<td>Puts Activity Theory into practice by generating research questions based on sub-activity triangles (i.e., decomposed models of human activity) that are used to support data gathering and analysis.</td>
</tr>
<tr>
<td>Stage 4 – Data collection and</td>
<td>Communicates research insight by modelling inter-relations of operational</td>
</tr>
</tbody>
</table>
Technique of Mapping Operational Processes
processes and by modelling study findings (e.g., contradictions identified in the analysis of human practices).

The Eight-Step Model of Stage 1 is a requirements capture methodology grounded in activity theory [10]. The model can be seen in Table 2.

Table 2: The Eight-Step Model (adapted from [10])

<table>
<thead>
<tr>
<th>Step</th>
<th>Identification of</th>
<th>Question to ask</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>Activity of interest</td>
<td>What sort of activity am I interested in?</td>
</tr>
<tr>
<td>2</td>
<td>Objective</td>
<td>Why is the activity taking place?</td>
</tr>
<tr>
<td>3</td>
<td>Subjects</td>
<td>Who is involved in carrying out this activity?</td>
</tr>
<tr>
<td>4</td>
<td>Tools</td>
<td>By what means are the subjects performing this activity?</td>
</tr>
<tr>
<td>5</td>
<td>Rules and Regulations</td>
<td>Are there any cultural norms, rules or regulations governing the performance of activity?</td>
</tr>
<tr>
<td>6</td>
<td>Division of Labour</td>
<td>Who is responsible for what, when carrying out this activity and how are the roles organised?</td>
</tr>
<tr>
<td>7</td>
<td>Community</td>
<td>What is the environment in which this activity is carried out?</td>
</tr>
<tr>
<td>8</td>
<td>Outcome</td>
<td>What is the desired outcome from carrying out this activity?</td>
</tr>
</tbody>
</table>

At Stage 2, the activity system needs to be decomposed into manageable sub-activities. Three rules-of-thumb, proposed by Mwanza, should be considered: (1) the actor is represented by the subject or community component of the activity system; (2) tools, rules, or division of labour function as mediators and (3) the activity needs to focus on an object. As a result of this stage, a triangle for each sub-activity is created [15].

At Stage 3, a research question for each sub-activity is generated. Here, either generic questions such as “What tools are used by the subjects to achieve their objects and how do they do that?” or questions specific to the context [15] such as “How does the software help the nurse to facilitate a high quality of chemotherapy administration?”

Based on these questions data should be collected and analysed. As a last step, the data needs to be interpreted by taking the contradictions of Activity Theory in consideration [15].

The intended result of AODM is to uncover contradictions. In a next step, these contradictions can then be taken as a basis to improve the system design. In order to solve the contradiction, elements of the activity system need to be adapted or changed. For instance, the division of labour is revised, new rules are introduced or tools need to be adapted. Another way of adapting the elements of an activity system is to support them with IT. Examples of IT support are the automation of routines supported by tools and providing data about the object or make the object manipulable. Linking work tasks of several people in order to create a community is another example of IT support [12].

3. Research Methodology

This research was developed using a qualitative research approach. Qualitative data were collected in two different procedures. First, the data collected in the study “Identifying Key Success Factors for the Adoption and Implementation of computerised physician order entry systems into the Australian Private Healthcare Sector” was taken into consideration. In this study, data were collected from literature synthesis in order to identify the influences of barriers, facilitators and critical factors for successful implementation such as behaviours at time of change, resources, or experiences and skills. In addition, a survey was executed with the users of the system in order to get a deeper understanding of interactions and dynamics from a clinical user perspective. In this survey 25 oncologists, 9 executive and Non users that have an access to the system, and 53 users (non-oncologists) were targeted [2]. Second, a case study with analysing one case was executed. Data about the chemotherapy process was collected by taking different literature into consideration.

The data collected from both of these procedures were then adapted to Activity Theory in order to get insights into the activity system of the process. This was done systematically using the adaptive mapping process described by Wickramasinghe and Goldberg [16]. As a result of the initial analysis, contradictions of the chemotherapy administration process were uncovered.

4. Mapping of Activity Theory

The outcomes will be presented focusing on the administration processes, the application of activity theory on these process and any contradictions.

4.1. Chemotherapy administration processes

It is necessary to consider the complete chemotherapy administration process even though only a system to support chemotherapy ordering is implemented. First, the chemotherapy ordering system covers not only the ordering process but also offers further functionality. Second, the activities around the chemotherapy ordering influence the chemotherapy ordering and therefore should be taken into account.
In general, chemotherapy administration is a four-stage process which consists of (1) prescribing of the drug, (2) preparation, (3) administration of the drug, and (4) post-chemotherapy assessment and follow-up [17]. The typical process for a patient undergoing chemotherapy starts with the diagnosis of cancer followed by the staging of complete information and the decision for a chemotherapy protocol. In order to prepare the patient initial monitoring tests, an oncologist visit, patient education, and patient assessment are executed. Then, the drug is given to the patient in a way that is depending on the type of chemotherapy [18, 19] which can be orally, intravenous, or an introduction of drugs directly into an organ or tissue affected by cancer [20]. The decision for a certain chemotherapy treatment is depending on the type of cancer and the prescribed drugs [21]. After the medication administration, the patient undergoes another monitoring before the cycle is finished. If more cycles are scheduled for this patient, the patient again enters the process at the point of patient education. The number, frequency, and duration of the cycles is depending on different factors such as type of cancer, extent of cancer, the types of drugs that are given, the expected toxicities of the drugs, and the amount of time necessary to recover from these toxicities [22]. Given this information, the complexity of the process can already be recognized. Taking a nurse’s, pharmacist’s, or physician’s perspective into consideration, the process of chemotherapy administration can also be modelled as illustrated in Figure 4.

4.2. The activity system of the chemotherapy administration process

In order to create the activity system of the chemotherapy administration process, the Eight-Step model, illustrated in Table 2 was used. The result can be seen in Figure 5.

Figure 5: Activity system of the Chemotherapy Administration Process (adapted from [2, 24, 25])

The complete process of chemotherapy was taken into consideration as the activity in order to present the whole picture and the influences on the chemotherapy ordering process.

The patient is defined as an object in this analysis. In general, it is recognized that the role of objects can change during the process. For instance, a patient is defined as an object if a physician evaluates the patient’s health. In contrary, a patient is a subject rather than an object when he or she is having a conversation with his or her physician [11]. However, as this analysis is focusing on the administration of chemotherapy, the patient is classified as an object. The objective of the activity is to ensure errorless treatment during the whole process of chemotherapy in order to improve the health of the patient.

Physicians, oncology nurses, and pharmacists were classified as the subjects. It is also mentioned in literature that other subjects such as fellows, house staff, or physician assistants take part in the activity and therefore are further complicating matters [24].

The community of the activity system is a private hospital that has specific characteristics. The physicians are Visiting Medical Officers (VMOs) that run independent, separate private practices. They are not salaried full-time staff and therefore are not subject to the usual line authority but have agreements with the hospital “[…] which are usually construed as broad duties rather than specific obligations or commitments to a particular work practice or IT system.” [2 p. 7].
Furthermore, there is a conventional commercial contract between the hospital and the pharmacies which means that also the pharmacy services are provided by an independent provider. It is important to mention that in the administration of chemotherapy only nurses and some administrative staff are fulltime salaried employees at the hospital [2]. The Division of Labour is illustrated in Table 3.

<table>
<thead>
<tr>
<th>Role</th>
<th>Responsibilities</th>
</tr>
</thead>
<tbody>
<tr>
<td>Nurse</td>
<td>Administers drugs [2] which also include tasks such as educating patients and managing side effects [17].</td>
</tr>
<tr>
<td>Private Physicians</td>
<td>Orders drugs [2] which also include tasks such as making treatment decisions and monitoring the effects of the treatment [26].</td>
</tr>
<tr>
<td>Pharmacist</td>
<td>Manufactures drugs [2] which also includes tasks such as the verifying the drug, clarifying identified discrepancies, and accurate dispensing of chemotherapy [26].</td>
</tr>
</tbody>
</table>

### 4.3. Contradictions

Next, associated questions such as “How do tools help subjects to facilitate the errorless chemotherapy treatment?” or “How do tools help the community to facilitate the errorless chemotherapy treatment?” are applied for each sub-triangle in order to ease the data gathering. As a result, literature revealed the following contradictions (Table 4). As an initial analysis was made and the community represents all participating subjects on the highest organizational level, there was no differentiation between subjects and community in the contradiction analysis.

<table>
<thead>
<tr>
<th>Sub-Triangles</th>
<th>Uncovered Contradictions</th>
</tr>
</thead>
<tbody>
<tr>
<td>Subject- Tool-Object and Community – Tool-Object</td>
<td>Human error e.g. wrong drugs, administering undertose or overdose [24]</td>
</tr>
<tr>
<td></td>
<td>Errors because of inherent properties of computerised system [24]</td>
</tr>
<tr>
<td></td>
<td>Errors involving misreading or misapplying source material [24]</td>
</tr>
<tr>
<td></td>
<td>Misinterpretation of hand-offs due to physician handwriting, miscommunication involving verbal orders, or other assumptions [24]</td>
</tr>
</tbody>
</table>

| Subject-Rules-Object and Community – Rules-Object | No single authoritative source for chemotherapy regimens (leads to oncologists creating customized order sets of commonly used regimens) [24] |
| Subject-Object-Division of Labour and Community-Division of Labour-Object | Misaligned and/or divergent goals due to multifaceted employment arrangements (nested principle agent relationships) [2] |

| Resistance of Change [2] |

### 5. Discussion

Activity Theory as used in this context has implications for theory and practice. Specifically, for theory Activity Theory enables the modelling of implementation requirements of a computerised physician order entry system of different user perspectives. Not only processes and technology are considered but there is also a high consideration of people – in Activity Theory as subjects and community – which are part of the activity.

Therefore, Activity Theory can be classified as an ontological framework in its own right or it can be combined with other theories to develop an expanded and more comprehensive ontological framework. Such a framework is used to analyse all interactions of healthcare stakeholders. In healthcare it contains the following stakeholders: researchers, clinicians, nurses, patients, and administrators. Partnerships between these stakeholders can be characterised by exchange of data, analysis, diagnosis, or treatment singly or in combination. The analysis of partnerships, media, purpose of collaboration, and technology is the aim of applying this framework [29].

The adoption of Actor Network Theory and Principle Agent Theory already uncovered key success factors and key barriers of the implementation of a computerised physician order entry system in the
Australian Healthcare sector. An example of an identified key barrier is the poor alignment of user goals with hospital goals and objectives [2].

For practice Activity Theory and the identification of contradictions provides a much richer picture of the chemotherapy administration process; thereby, enabling changes to be made to clinical practice to ensure optimal care outcomes.

The next step is to test this model using a large dataset of patients.

Applying Activity Theory offers several more benefits. “Information systems should be able to support active individuals while still preserving the organizational viewpoint.” [8 p. 371]. As the activity system considers all stakeholders and relationships of the activity, not only all participating individuals but also the organizational viewpoint will be illustrated.

In addition, each relationship (or triangle) can be analysed separately in order to get insights of problems and potential barriers. These uncovered contradictions build the basis to develop measures for maintaining the relationship between the individual and social levels.

Furthermore Activity Theory can bridge the gap between motivation and action of an activity [9]. A combined analysis of motivations, goals, and operations is illustrating Why, What, and How things are done [9].

It is also important to mention that Activity Theory is multidisciplinary and therefore activities are considered by different disciplines depending on the context they are creating [8] e.g. healthcare, information systems, change management.

For completeness, we note that this is one of the first studies to use Activity Theory to model a healthcare context, more confirmatory work is required to truly demonstrate its full power and potential in this regard.

6. Conclusion

The preceding has served to illustrate the benefits of using Activity Theory as a rich and robust lens to examine the critical issues when implementing a computerised system into a clinical context; specifically, a chemotherapy ordering system into a private healthcare setting. We believe such an analysis will augment the benefits provided by other theories such as Actor Network Theory and Principle Agent Theory and taken together will ensure and enable the successful assimilation of the new computerised solution into daily practice. Our future research will serve to provide confirmatory evidence of this.

7. References


