SOCIO-COGNITIVE ENGINEERING OF HUMAN-AGENT PARTNERSHIPS

TNO innovation for life

TU Delft
Delft University of Technology

Mark Neerincx

TNO Perceptual and Cognitive Systems

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TU Delft: Interactive Intelligence

Mission

- Understand and engineer human-agent collaboration.

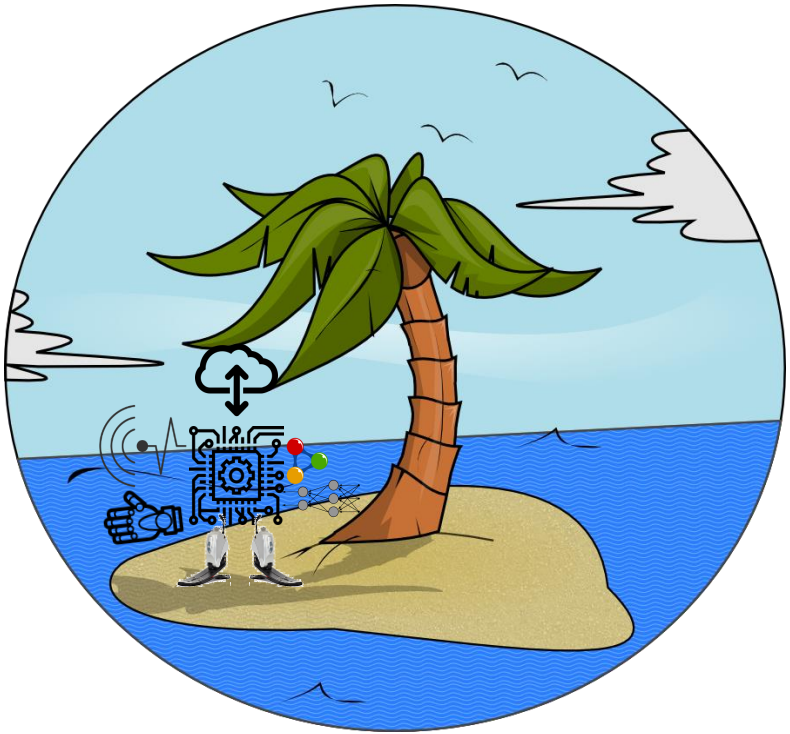
Research

- Develop theories, models and methods of interactive intelligence by combining intelligent agent technology, cognitive engineering, psychology, affective computing, value sensitive design and human-computer interaction.

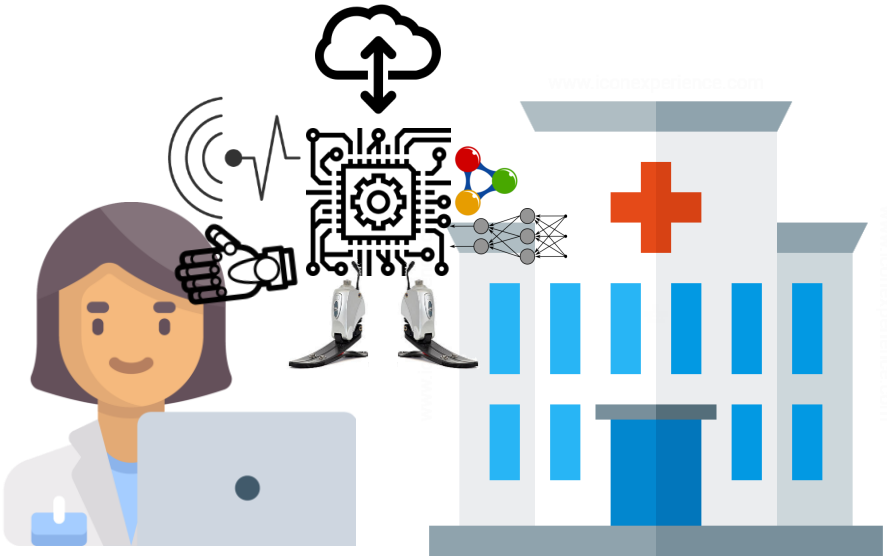
Research Themes

- Autonomous decision systems
- Cognitive-affective agents
- Behaviour change support systems
- Electronic Partners

DEVELOPING ARTIFICAL INTELLIGENCE (AI)…



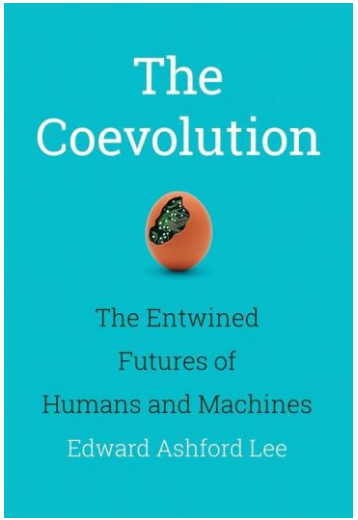
DEVELOPING SOCIAL AI…

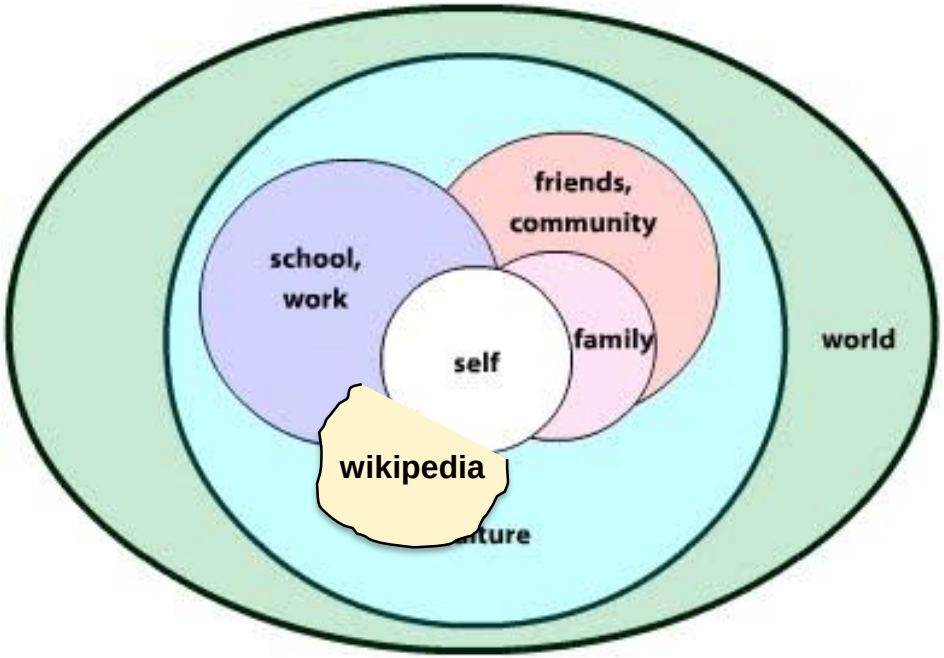


HUMAN INTELLIGENCE IS SOCIALLY SITUATED

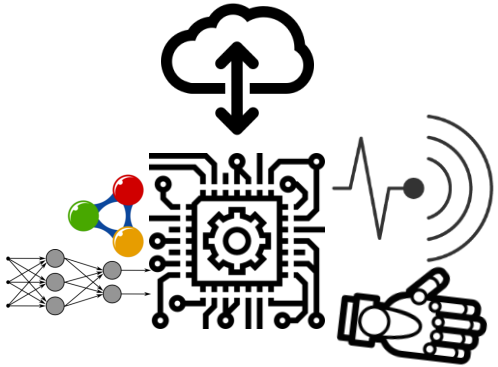
Situated Embodied Cognition:

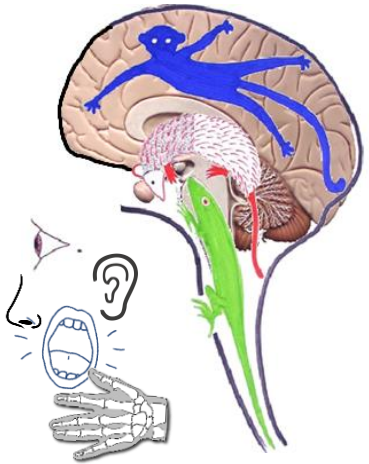
- Cognition is an embodied process; social, distributed, enacted, and often works without representations.
- Knowing exists, ***in situ***, inseparable from context, activity, people, culture, and language.





ARTIFICIAL AND HUMAN INTELLIGENCE





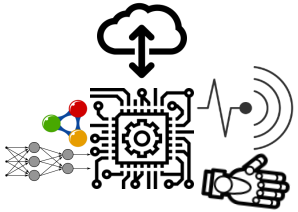
Artificial Intelligence:

- Symbolic Reasoning: Knowledge-driven, semantics, logic, …
- Machine Learning: Data-driven…

Human Intelligence (Dual Process Theory):

- Recent: Slow, sequential, deliberate, abstract reasoning, limited capacity…
- Old: Rapid, parallel, automated, associative…

ARTIFICIAL AND HUMAN INTELLIGENCE



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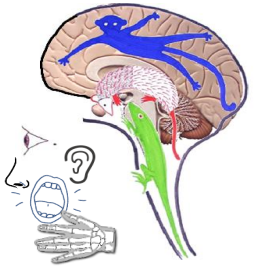
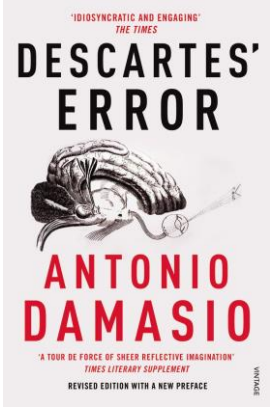


Artificial Intelligence:

- Can be copied infinitely
- Algorithmic, computational: Time does not change the process
- Digital
- Meta-cognition?



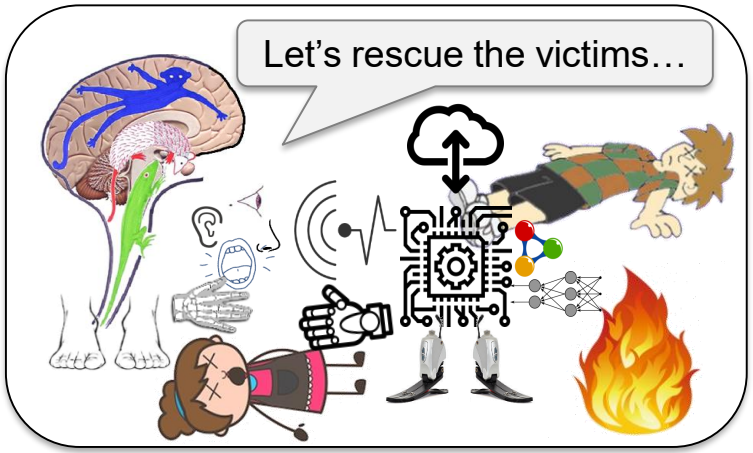
Human Intelligence:

- Not only the neural connections determine the processing (chemicals…)
- Complex structure and location of connections: Time affects the process
- Continuous (or digital)?
- Meta-cognition (“think about thinking”)
- And emotion…

HOW TO DEVELOP HYBRID INTELLIGENCE?

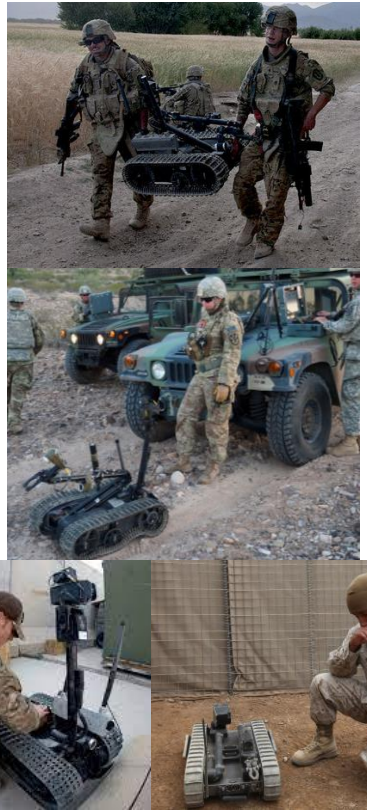
- Develop theories, models and methods for the co-evolution of humans, robots and agents as a joint normative socio-cognitive system.

- Harmonize the interdependent social, cognitive, and affective processes for performance and well-being (e.g., defined as patterns).



HUMAN-ROBOT RELATIONSHIPS…

- Anecdotes of Explosive Ordnance Disposal (EOD) operators in Iraq and Afghanistan:
  - robots were assigned names and gendered identities
  - when a robot was damaged, its loss was grieved, sometimes accompanied by funeral-like rituals
  - when a robot had to be repaired, its operators requested to fix, instead of replace, its mechanical parts, to preserve the robot's individual identity
  - in rare occasions, soldiers have endangered themselves to protect the robot from enemy assaults



Carpenter, J. (2013). *The Quiet Professional: An investigation of US military Explosive Ordnance Disposal personnel interactions with everyday field robots* (Doctoral dissertation, University of Washington)

A NEW BREED OF PARTNERS IN CARE…

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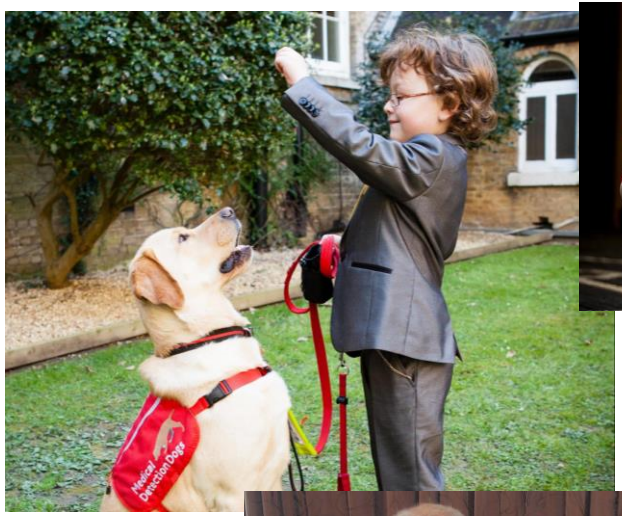

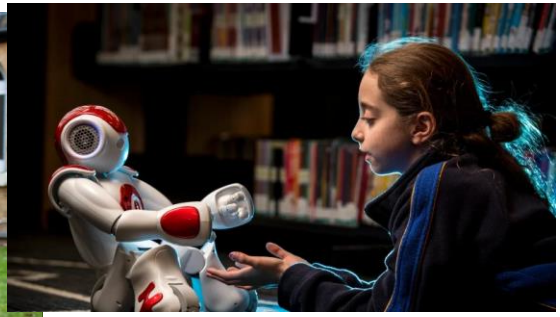

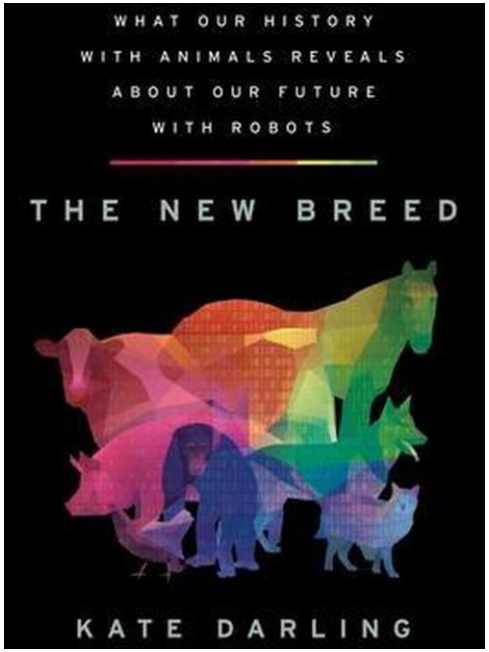

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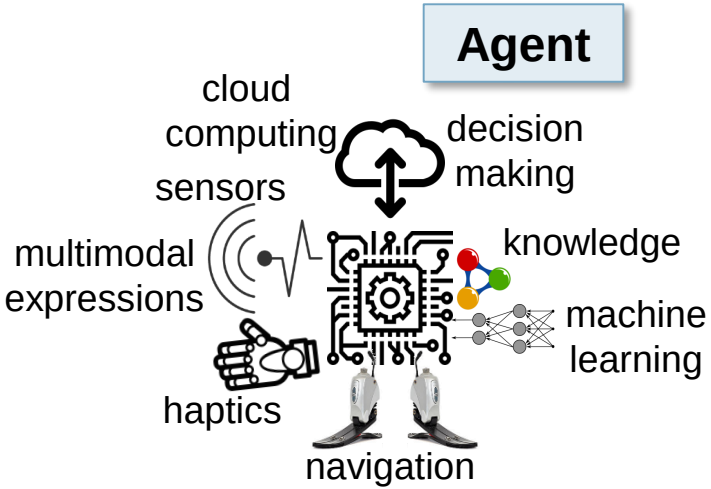
A NEW BREED OF PARTNERS IN CARE…



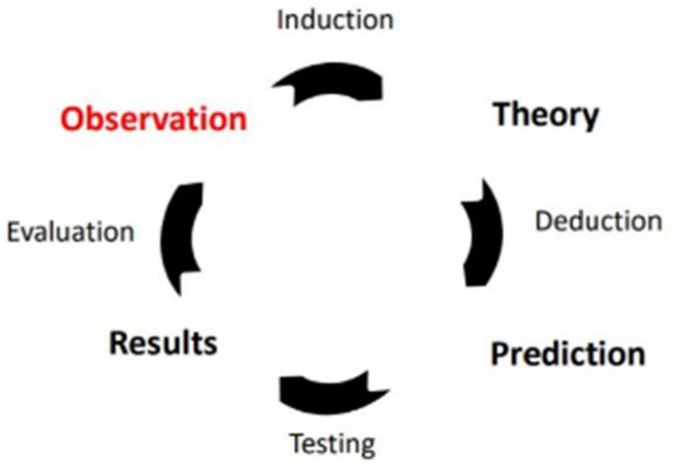
- New ways of working together are emerging
- with new kinds of relationships
- and new opportunities to learn, adapt & coordinate

PARTNER: PAL EXAMPLE

https://player.vimeo.com/video/111724122

- http://www.pal4u.eu/
- M.A. Neerincx *et al.* (2019). Socio-Cognitive Engineering of a Robotic Partner for Child's Diabetes Self-Management. *Frontiers in Robotics and AI*, 6:118. https://doi.org/10.3389/frobt.2019.00118

THE R&D METHOD: SOCIO-COGNITIVE ENGINEERING



frontiers

Socio-Cognitive Engineering of a Robotic Partner for Child's Diabetes Self-Management

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ABSTRACT

Social or humanoid robots do hardly show up in "the wild", aiming at pervasive and enduring human benefits such as child health. This paper presents a socio-cognitive engineering (SCE) methodology that guides the ongoing research & development for an evolving, longer-lasting human-robot partnership in practice. The SCE methodology has been applied in a large European project to develop a robotic partner that supports the daily diabetes management processes of

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disease (children could use it up to 6 months; the robot in the hospitals and diabetes camps, and its avatar at home). It represents a new type of human-agent/robot systems with an evolving

Neerincx, M. A., van Vught, W., Blanson Henkemans, O., Oleari, E., Broekens, J., Peters, R., Kaptein, F., Demiris, Y., Kiefer, B., Fumagalli, D. & Bierman, B. (2019). Socio-cognitive engineering of a robotic partner for child's diabetes self-management. *Frontiers in Robotics and AI*.

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DESIGN RATIONALE

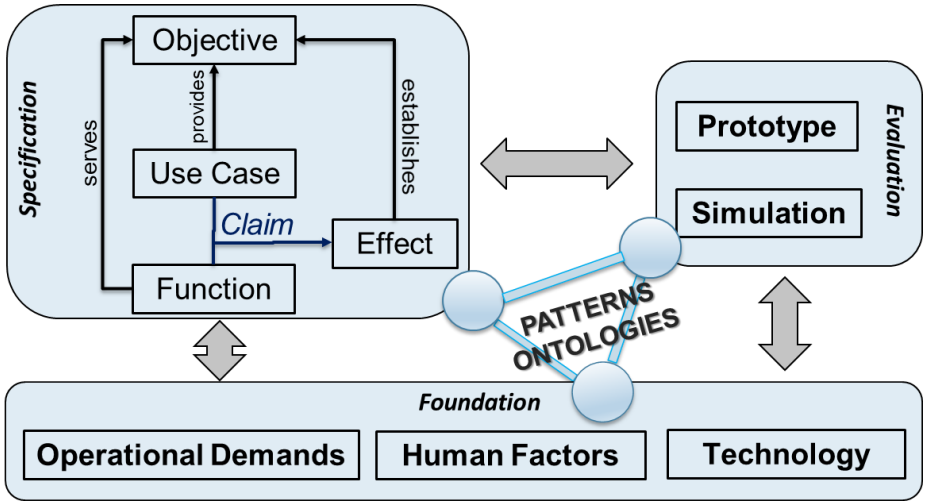
- An explicit documentation of the design decisions *with* the reasons behind these decisions.
- Providing an argumentation-based structure to key design problems as a means to record and communicate the argumentation and reasoning behind the design process:
  - the reasons and argumentation behind a design decision
  - its justification
  - possible alternatives considered
  - the trade-offs evaluated

- When the reasons, argumentation and justification refer explicitly to theories, the design rationale can be viewed as a specification of multi-disciplinary theory, guiding scientific research
- By explicitly referring to the use cases, the design rationale (and its underlying theory) is situated.

R&D OF HUMAN-AGENT SYMBIOSIS

- The challenge is to, **intradisciplinary**, study **long-term** human-agent **collectives** in the **wild**, addressing the **interdependencies** and **dynamics**.
- We need a common vocabulary, taxonomy or **ontology** to define and reason about core concepts of the symbiosis theories, models, methods and artefacts (incl. meta-cognition).
- We need to learn and continue successful symbiosis **patterns**.
- We need to **share** data, models, design rationales, …

This is called Socio-Cognitive Engineering.



SOCIO-COGNITIVE ENGINEERING

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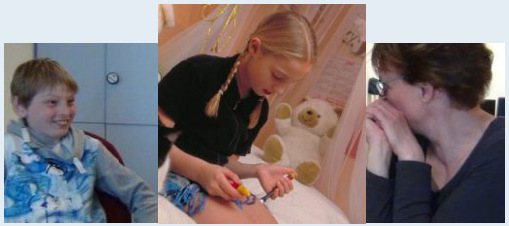
Coherent Set of Use Cases, Functions & Claims

Design Patterns

Foundation

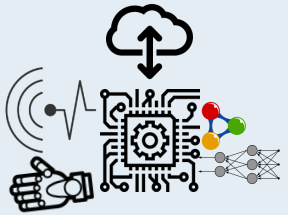


Operational Demands

People
Activities
Context

Human Factors

Theories
Methods
Guidelines



Technology

Principles
Frameworks
Standards

OPERATIONAL DEMANDS

http://www.pal4u.eu/

Diabetes Type 1

- ~130,000 children (<14, Europe , 2013)
- Deregulation of blood glucose
- Decreased well-being

Self-Management Needs

- Life-long discipline
- Feelings of exclusion
- Diverse personal & social factors
- Transition from childhood to adolescence

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OPERATIONAL DEMANDS

Diabetes

Metabolic disease ~ high blood sugar

- pancreas does not produce enough insulin
- cells do not respond to the insulin that is produced.

Symptoms

- frequent urination
- increased thirst
- increased hunger

Objective: Long-term support for children with T1DM

- **People**: Children with T1DM, parents, diabetes nurses, dieticians, …
- **Activities**: Learn why/how to cope with T1DM, check blood glucose, administer insulin, keep diary, …
- **Contexts**: Hospital, diabetes camp, home, …

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OPERATIONAL DEMANDS

Stakeholders:

- ***Direct***: Refer to individuals who interact directly with the technology.
  - Children with T1DM, Parents, Health Care Professionals.
- ***Indirect***: Refer to other individuals who are otherwise affected using the technology.
  - Children's peers, school teachers, sport coaches, …

Values:

- "The principles or standards of a *person* or *society*, the personal or societal judgment of what is valuable and *important* in life." (Oxford English Dictionary)
- "[…] are typically associated with what is '*good*' or '*desirable*', […] are *normative*." (van de Poel, 2020)
- E.g., autonomy, health, privacy, …

OPERATIONAL DEMANDS

- Requirements Engineering makes use of user stories to capture requirements in natural language
- User Story:
  - *As a <role> I want <something> so that <reason>*
- **Value Story**:
  - *As a <stakeholder> I want <function> to support <value>*
- Example: As a child with diabetes I want to learn blood glucose checking with a playfellow to support autonomy

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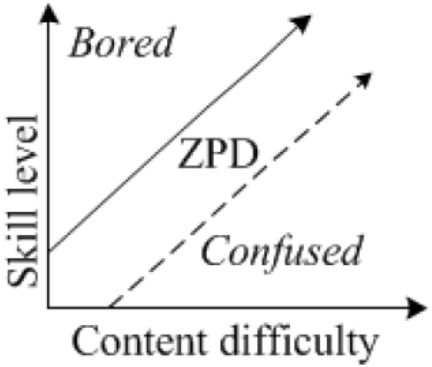
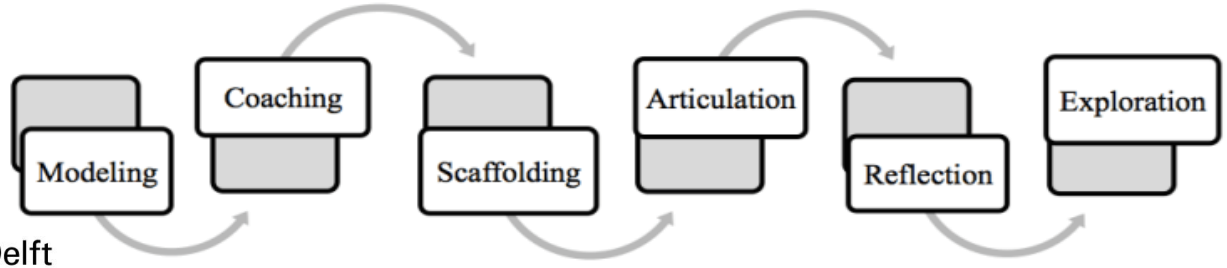
Collaborative Learning

- Knowledge can be created when persons actively interact by knowledge exchange, sharing experiences, and taking asymmetric (e.g., teaching / learning) roles
- Rooted in Vygotsky's (1896–1934) theory ("an inherent social nature of learning")
- Educator's role is to give children experiences that are within their **Zones of Proximal Development ZPD**, thereby advancing their individual learning
- Reciprocal Teaching supports "**learning by teaching**" and "**cognitive apprenticeship**"

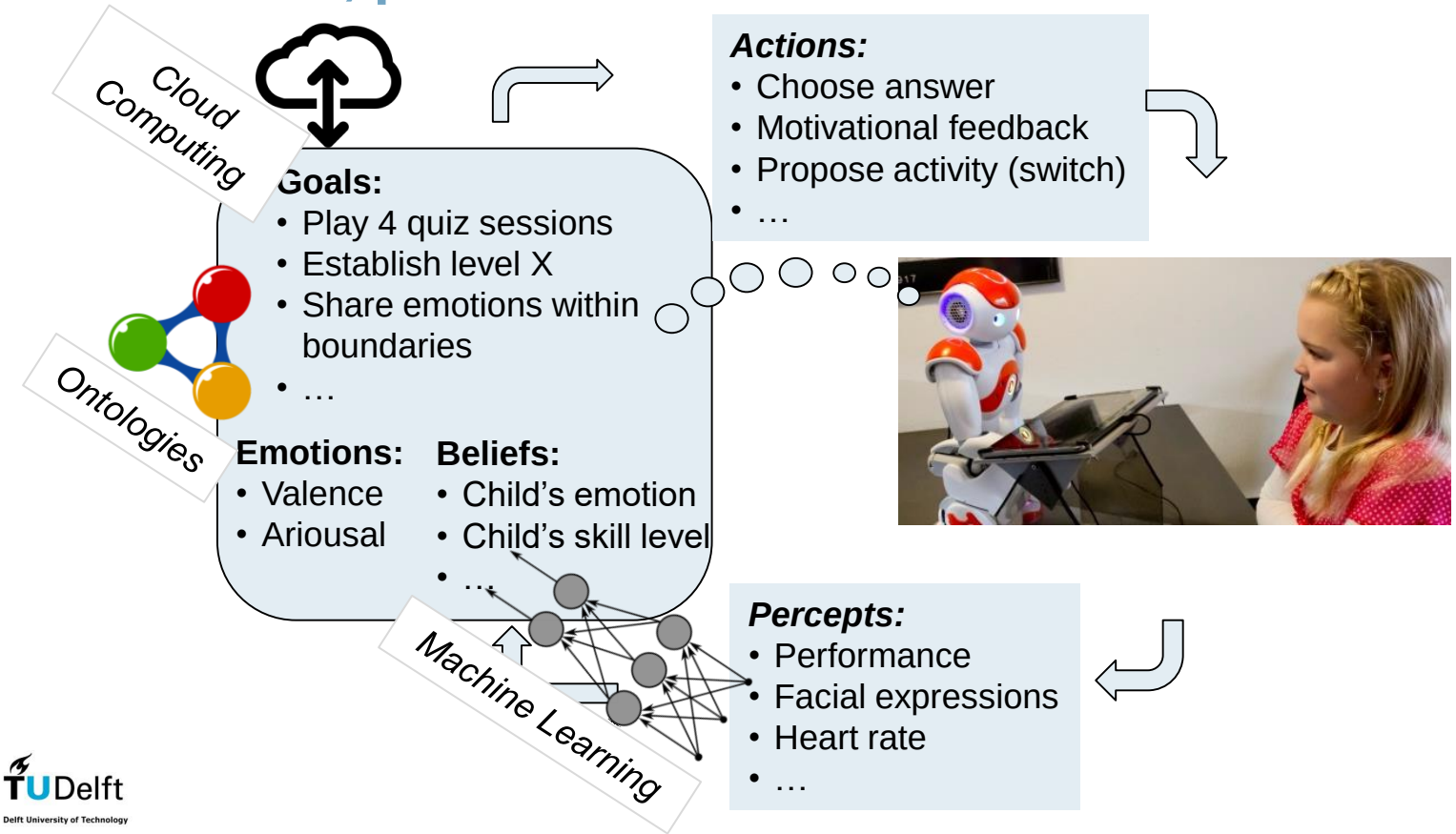


Theories – underpin design!



TECHNOLOGY

intentional, personalized and affective



SOCIO-COGNITIVE ENGINEERING

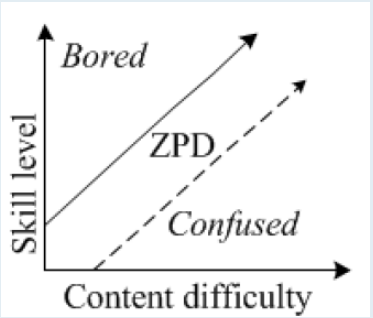
Coherent Set of Use Cases, Functions and Claims

Foundation

Value Stories
Learning about diabetes
Self-management before puberty

Operational Demands

Zone of proximal development
Behavioural change

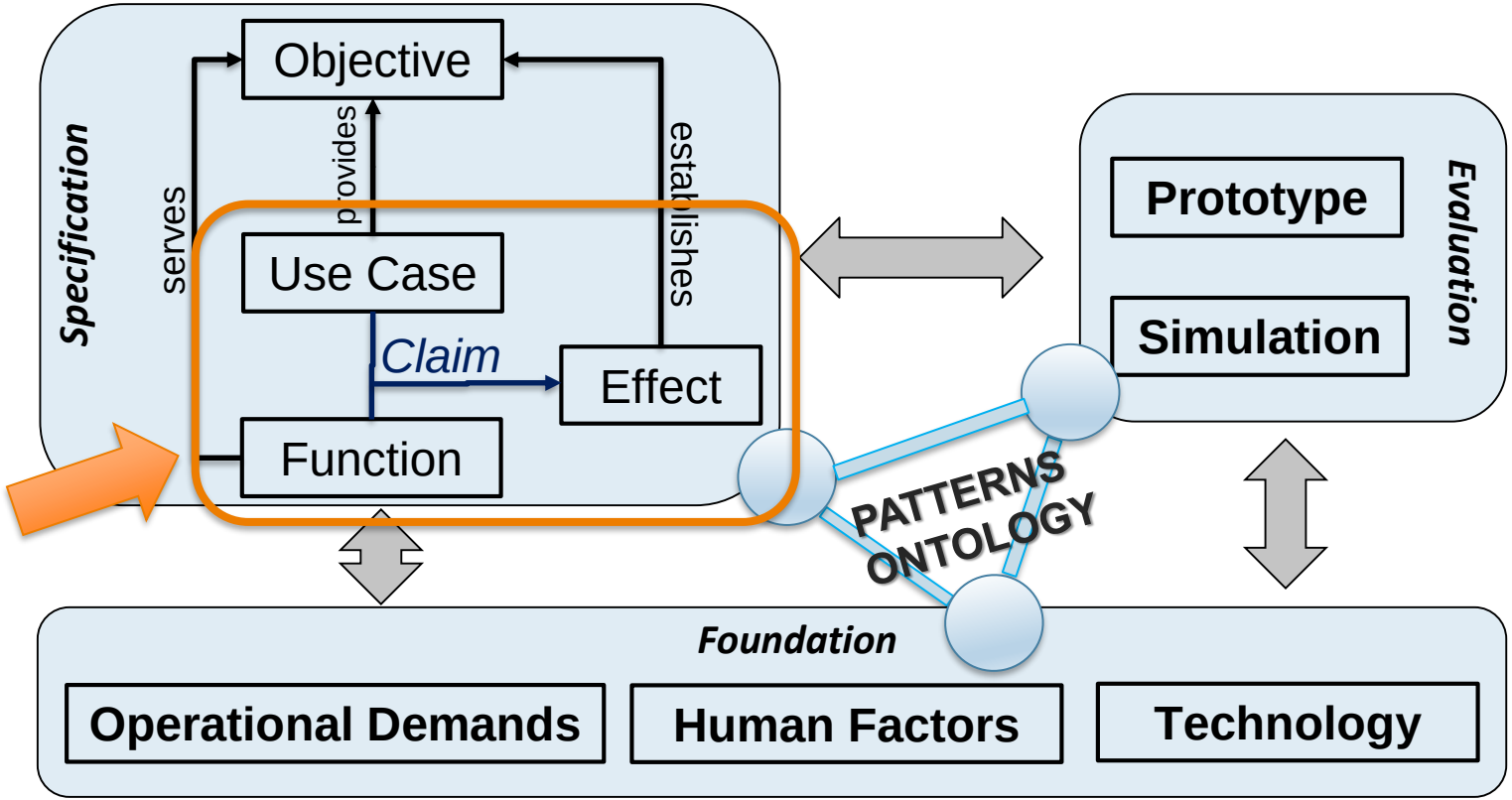


Human Factors

Agents / ePartners
User modelling
Robotics
Affective computing
Mobile games

Technology

SOCIO-COGNITIVE ENGINEERING



CLAIM PERSONALIZATION

Turning Tablet Pattern

Quiz

Use Case

Function

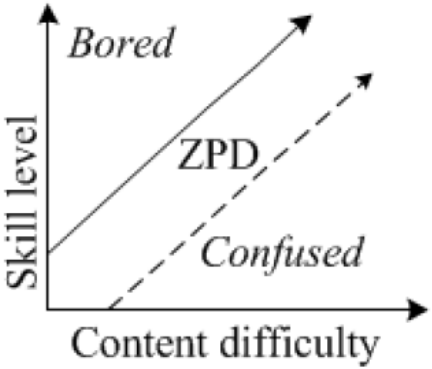
Effect

claim

+ Child is intrinsically motivated to perform the activity due to the tailored challenge

The robot shall attune the assignments to child's performance

- Some children may not reach the minimal performance within the available time due to a (personal) long learning curve.



RESULTS

Free-choice period with the adaptive robot:

- Children chose to play the quiz for a longer period

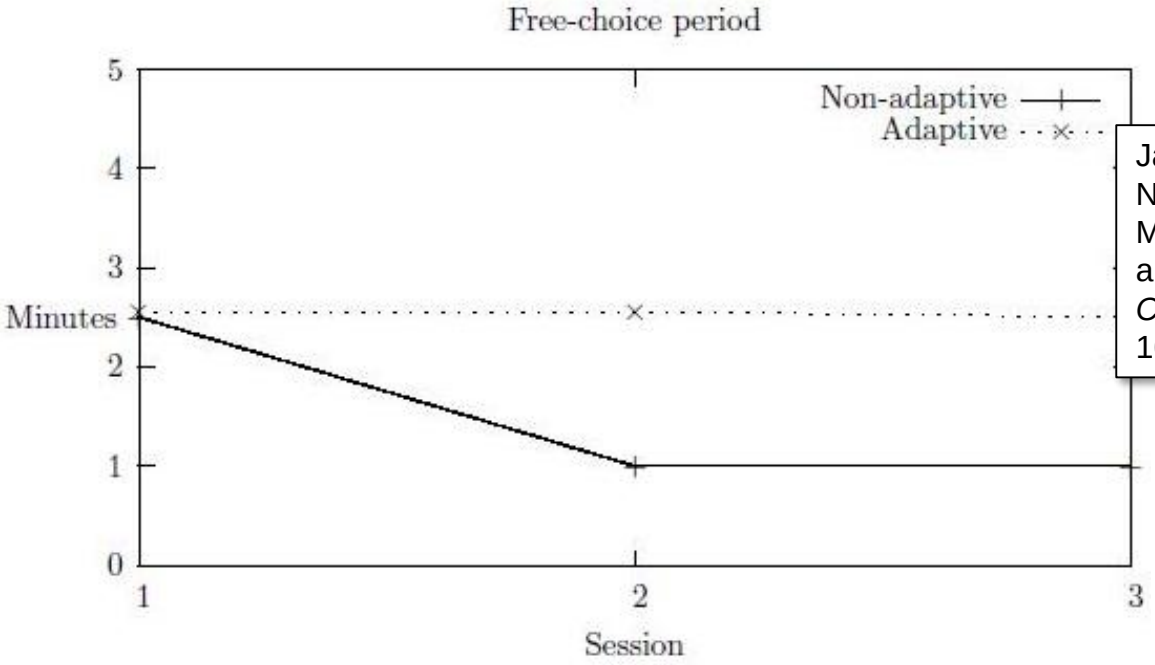
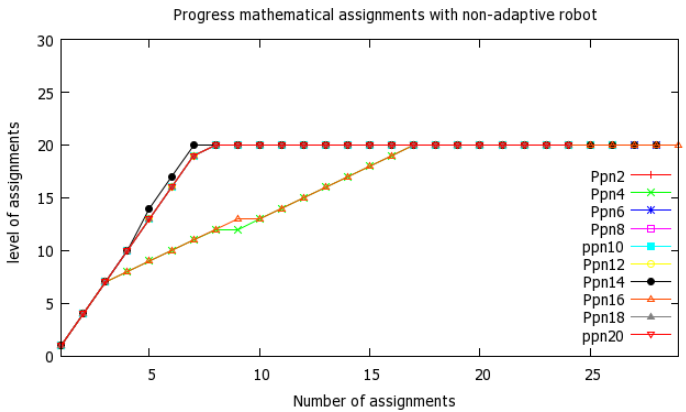


Figure 4.4: Amount of time spend with robot during free-choice period

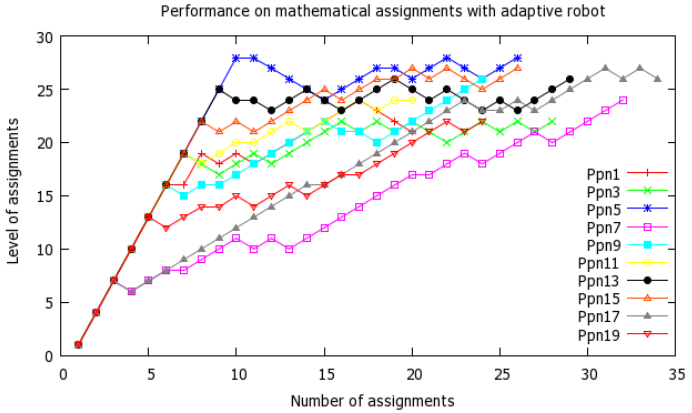
Janssen, J. B., van der Wal, C. C., Neerincx, M. A., & Looije, R. (2011). Motivating children to learn arithmetic with an adaptive robot game. In *International Conference on Social Robotics* (pp. 153-162). Springer, Berlin, Heidelberg.

RESULTS

Overall: Slow starters played with robot during free-choice period



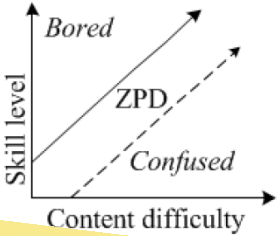
- Average level 20 (as was designed)



- Average level 24,7
- Children converged to their level over the different sessions

CLAIM PERSONALIZATION

Turning Tablet Pattern



Quiz

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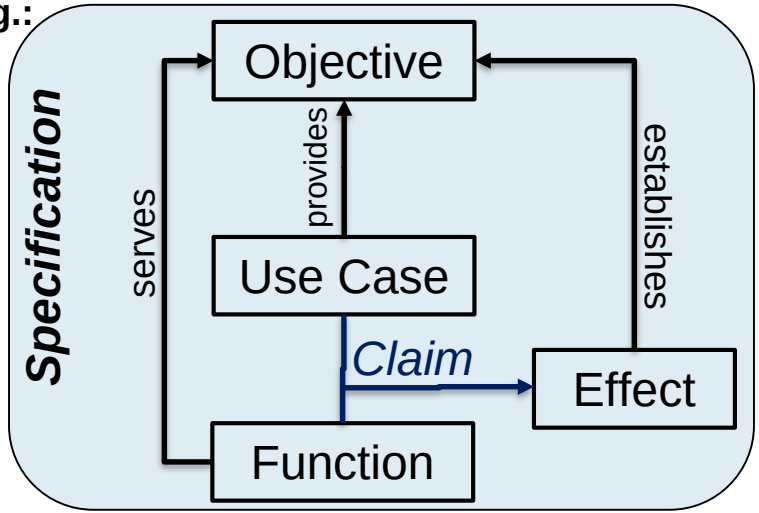
SOCIO-COGNITIVE ENGINEERING

Self-Determination Theory

Objectives, e.g.:
- Competence
- Autonomy
- Relatedness

Use cases, e.g.:
- PAL Activities
  - Quiz
  - Break & Sort
  - Memory
  - Video watching
- Getting to know PAL
- Selection of objectives
- Managing the time-line
  - Redeeming credit points
  - Providing information
  - Tracking progress



Functions, e.g.:
- Explanations
  - e.g., contrastive, deliberative
- Feedback
  - e.g., informative, motivational
- Experience sharing
  - e.g., mutual self-disclosure

Effects, e.g.:
- Health
  - e.g., Hb1AC
- DM Performance
  - e.g., progress on objectives
- Knowledge
  - e.g., answers quiz questions
- Motivation
  - e.g., free choice period
- Preferences
  - "Tangible" questionnaires

PAL CYCLI

Cycle	Foundation	Core functions	UC implementation	Claims
1	Self-determination theory, zone of proximal development, gamification, ALIZ-E design rationale. Value stories, journey maps, co-designed scenarios. Cloud computing, hybrid AI and federated ontology.	*R1*: PAL shall provide learn-by-playing activities with personal, reliable and reinforcing assistance on diabetes management. *R2*: PAL actor shall show empathic partnership. *R3*: PAL shall support joint planning and pursuing personalized objectives.	*Robot interaction*: Acquaintance, quiz. *MyPAL environment*: Avatar, timeline and quiz. *Dashboards*: PAL control and inform.	*C1*: Child has increased knowledge on T1DM. *C2*: Child likes the PAL actor (robot and its avatar). *C3*: Child experiences diabetes-related activities more positively.
2	Social penetration theory, motivational interviewing, folk psychology. New co-designed scenarios. System reliability, usability engineering for children.	*R4*: PAL actor shall share experiences via mutual self-disclosure. *R5*: PAL actor shall provide feedback and explanations on behavior. *R6*: PAL actor shall show personalized learning styles	*Robot interaction*: Break and sort game. *MyPAL environment*: Dialogues, reward system (earn coins) and a shop.	*C4*: Child bonds with the PAL actor via the robot *and* its avatar. *C5*: Child is motivated to work on his or her personal objectives with PAL.
3	Expert knowledge on child's learning processes for diabetes management with culture- and hospital dependencies. New co-designed scenarios. Game-based learning.	*R1.1*: PAL's support for planning and pursuing objectives shall be personalized and harmonized to child's daily life. *R7*: PAL shall propose and	*PAL actor*: Small talk, dancing designed by child. *MyPAL environment*: Tip of the day, memory games (3), videos, real world tasks, high	*C1.1*: Child has increased situated knowledge on T1DM. *C6*: Child is aware of T1DM state and causes and develops self-efficacy

EVALUATION (RCT): PAL VS. CARE-AS-USUAL

- 3 hospitals (2 NL + 1 IT)
- 49 children / families
- 10 HCPs (5 NL + 5 IT)
- 2 x 3 month period

Three human basic needs (Self-Determination Theory):

- *Competence*: Enhanced knowledge
  More PAL usage => more knowledge.
- *Relatedness*: Children liked the PAL-robot
  and motivated to interact.
- *Autonomy*: Enhanced subjective self-care,
  particularly younger children

Health condition:

- *Subjective*: Enhanced diabetes-related quality of life
- *Objective*: ? More healthy blood glucose levels

THE SCE OUTCOME:

HUMAN-AGENT PARTNERSHIP BEHAVIORS

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Leren met Charlie

Een robotmaatje voor kinderen met diabetes

Learning with Charlie

A robotpal for children with diabetes

PAL

PERSONAL ASSISTANT FOR HEALTHY LIFESTYLE

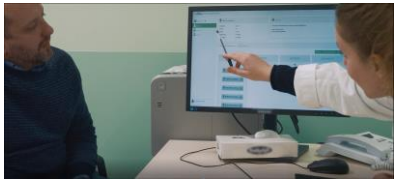
SUGAR KIDS CLUB

PAL system

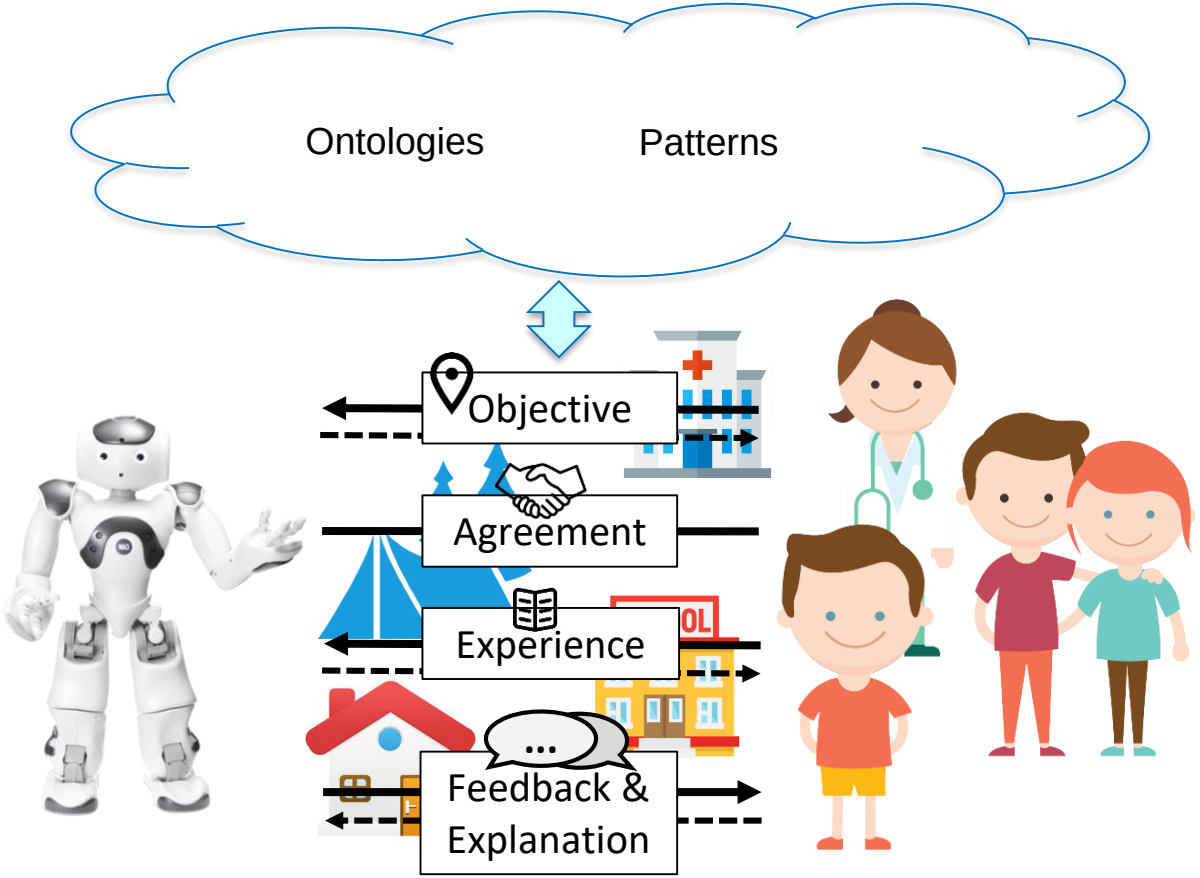
- Robot / Avatar
- Time-line
- Games
- Dashboards

Direct stakeholders

- Child with T1DM
- Parents
- Caregivers



HUMAN-ROBOT PARTNERSHIP

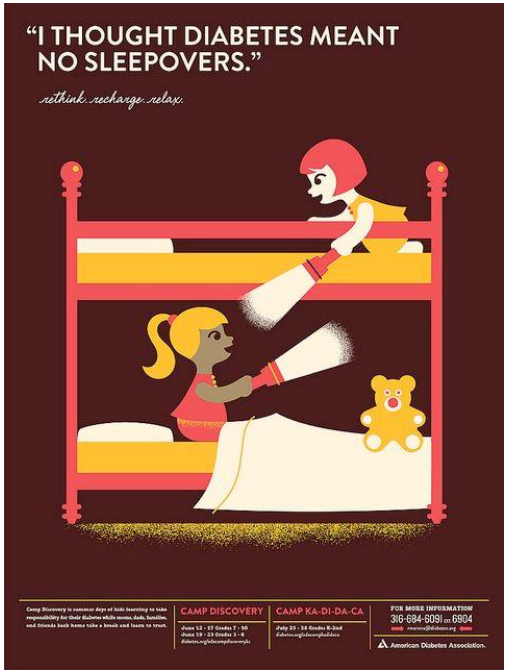


COMMON SITUATED OBJECTIVES

TNO innovation for life

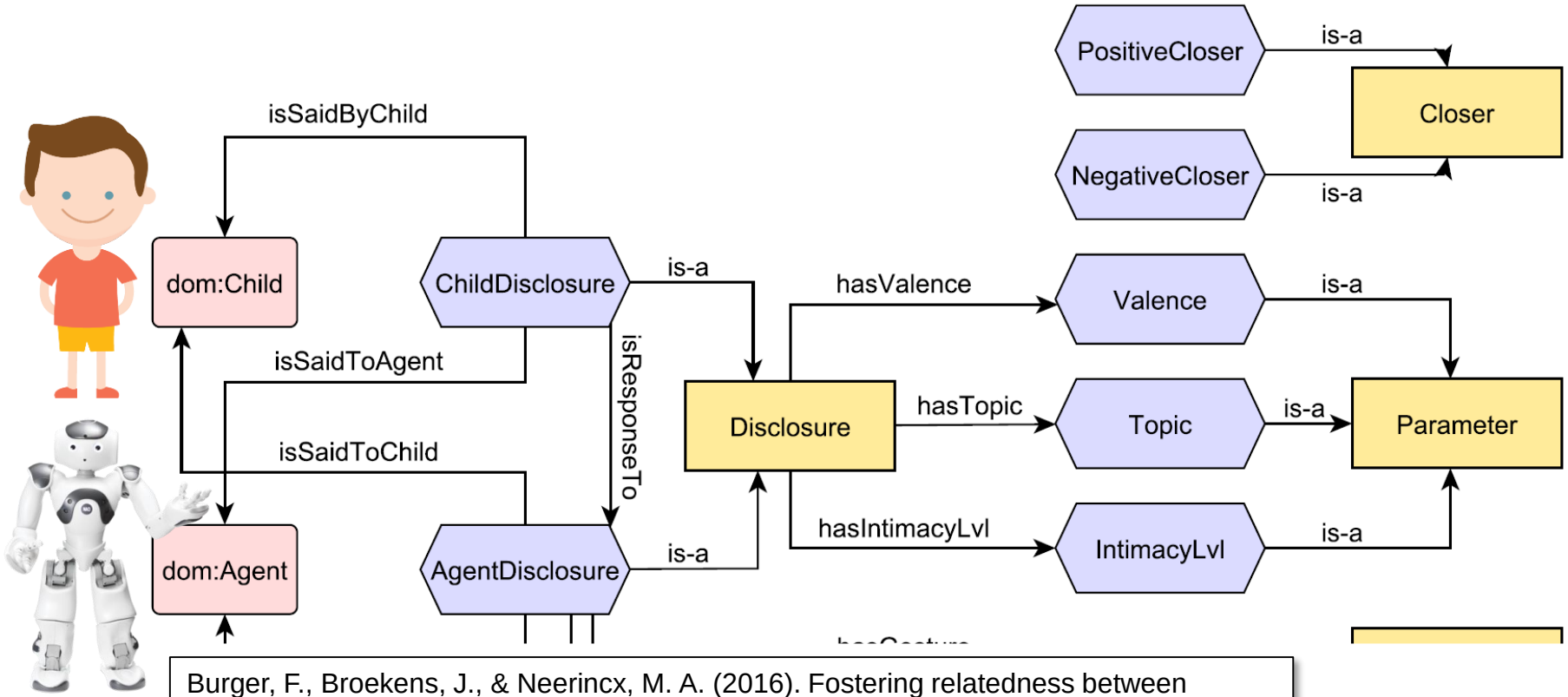
Collaborative objective selection for motivation & learning

- An objective consists of:
  - Achievement (e.g., “I can have a sleepover at relatives”)
  - Goal (e.g., “I know how to inject myself” and “I know what to take with me for a stay with someone else”)
  - Task (e.g., “Watch a video on insulin injection”, “Answer a quiz question on what is the best place to inject”).
- Progress:
  - Tasks => Goals => Achievement.



Peters, R., Broekens, J., & Neerincx, M. A. (2017). Guidelines for Tree-based Collaborative Goal Setting. In *Proceedings of the 22nd International Conference on Intelligent User Interfaces* (pp. 401-405)

PARTNER SHARING EXPERIENCES EXAMPLE



Burger, F., Broekens, J., & Neerincx, M. A. (2016). Fostering relatedness between children and virtual agents through reciprocal self-disclosure. In *Benelux Conference on Artificial Intelligence* (pp. 137-154). Springer, Cham.

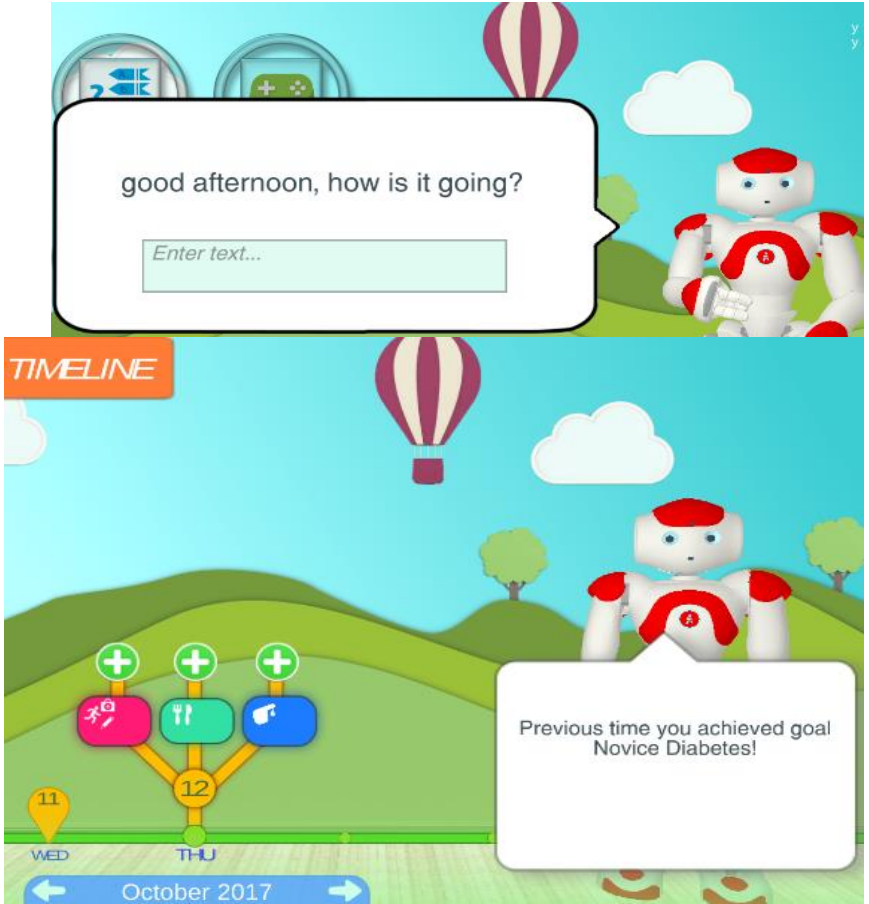
SHARED EXPERIENCES

Episodic Memory

Episode class:
- When
- Where
- Who
- Why
- What
- How

Episode instantiation, e.g.:
- Goal Was Too Difficult
- Goal Almost Achieved

Episode trigger, e.g.:
- On Child Login
- QuizCompleted



AGREEMENTS

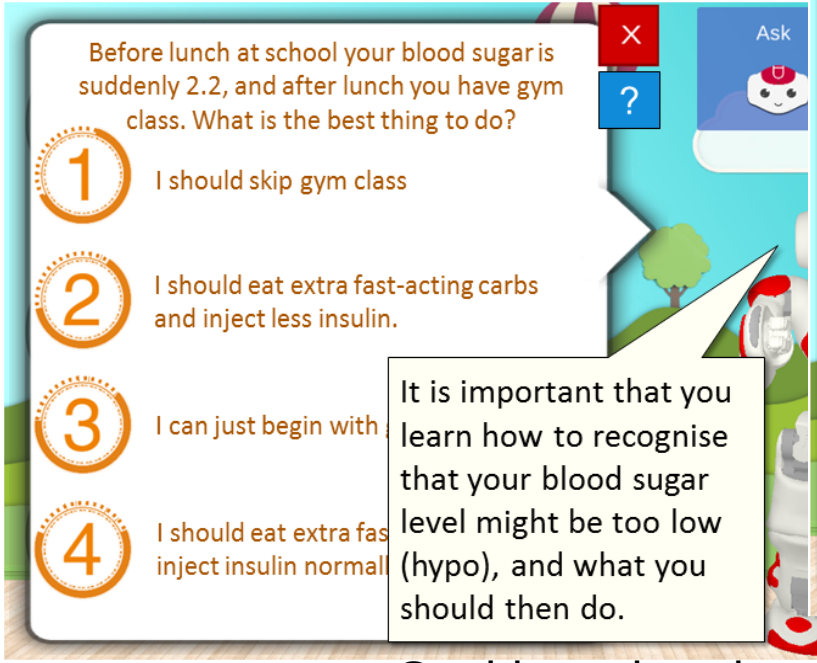
- **Policies**
  - formal specifications of permissions, prohibitions & obligations for agent's behavior
    - to constrain agent's behavior to norms
    - to construct and govern ***agreements***

- **Example agreements**

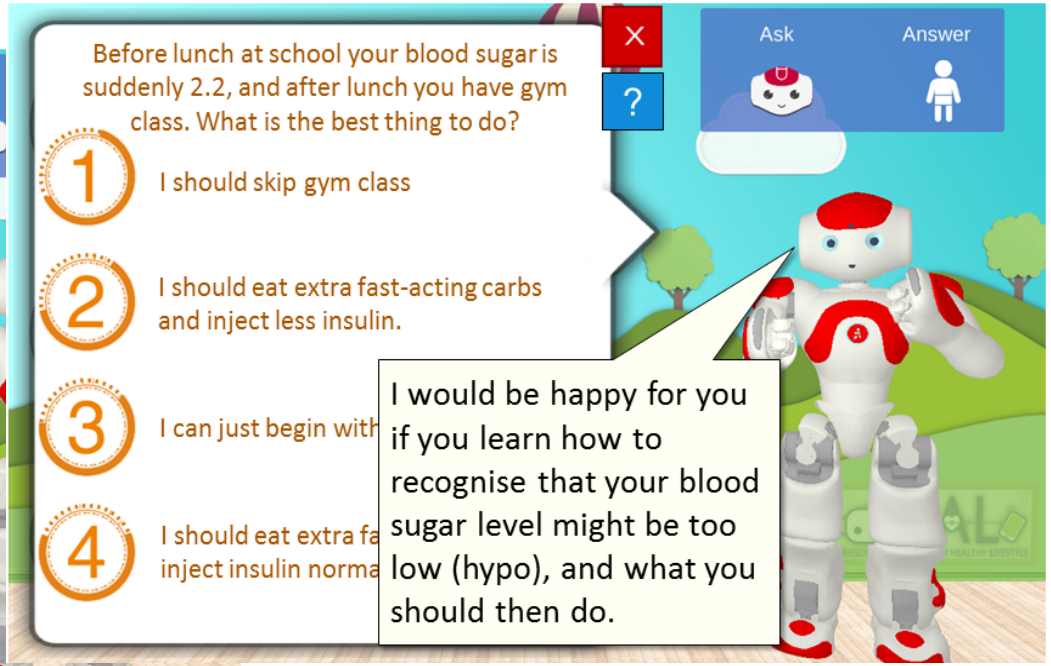
Condition	Action	When
risky blood glucose level	inform parent and HCP	always
normal glucose level	Inform parent and HCP	adjustable
negative emotion	Inform parent	adjustable

UPTAKE & LEARNING BY EXPLANATION

- Explaining ***why*** to do specific tasks…



Goal-based explanation



Emotion-based explanation

UPTAKE & LEARNING BY EXPLANATION

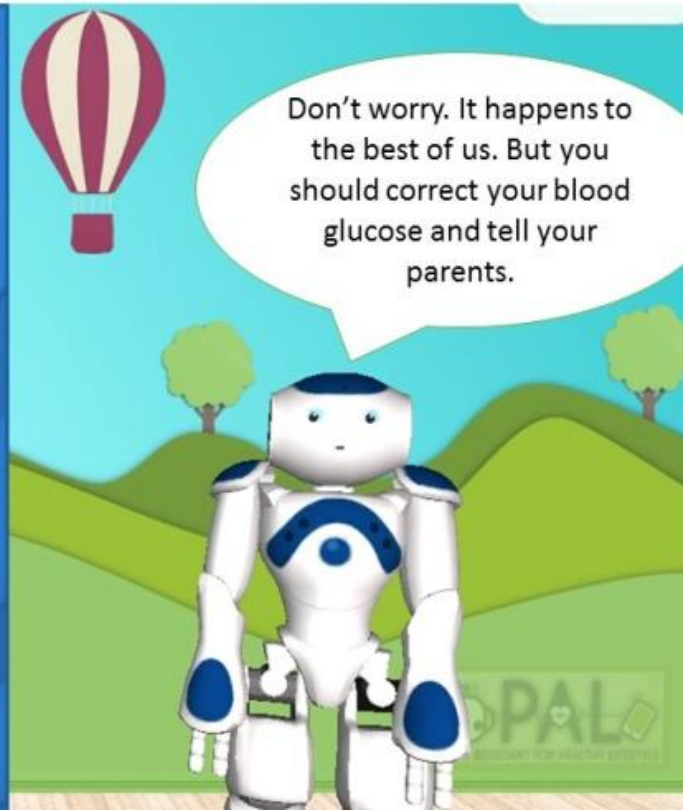
I hope you learn the basic characteristics of diabetes, and some practical facts. So, let's do the first activity.

Kaptein, F., Broekens, J., Hindriks, K., & Neerincx, M. (2019). Evaluating Cognitive and Affective Intelligent Agent Explanations in a Long-Term Health-Support Application for Children with Type 1 Diabetes. In *2019 8th International Conference on Affective Computing and Intelligent Interaction (ACII)* (pp. 1-7). IEEE.

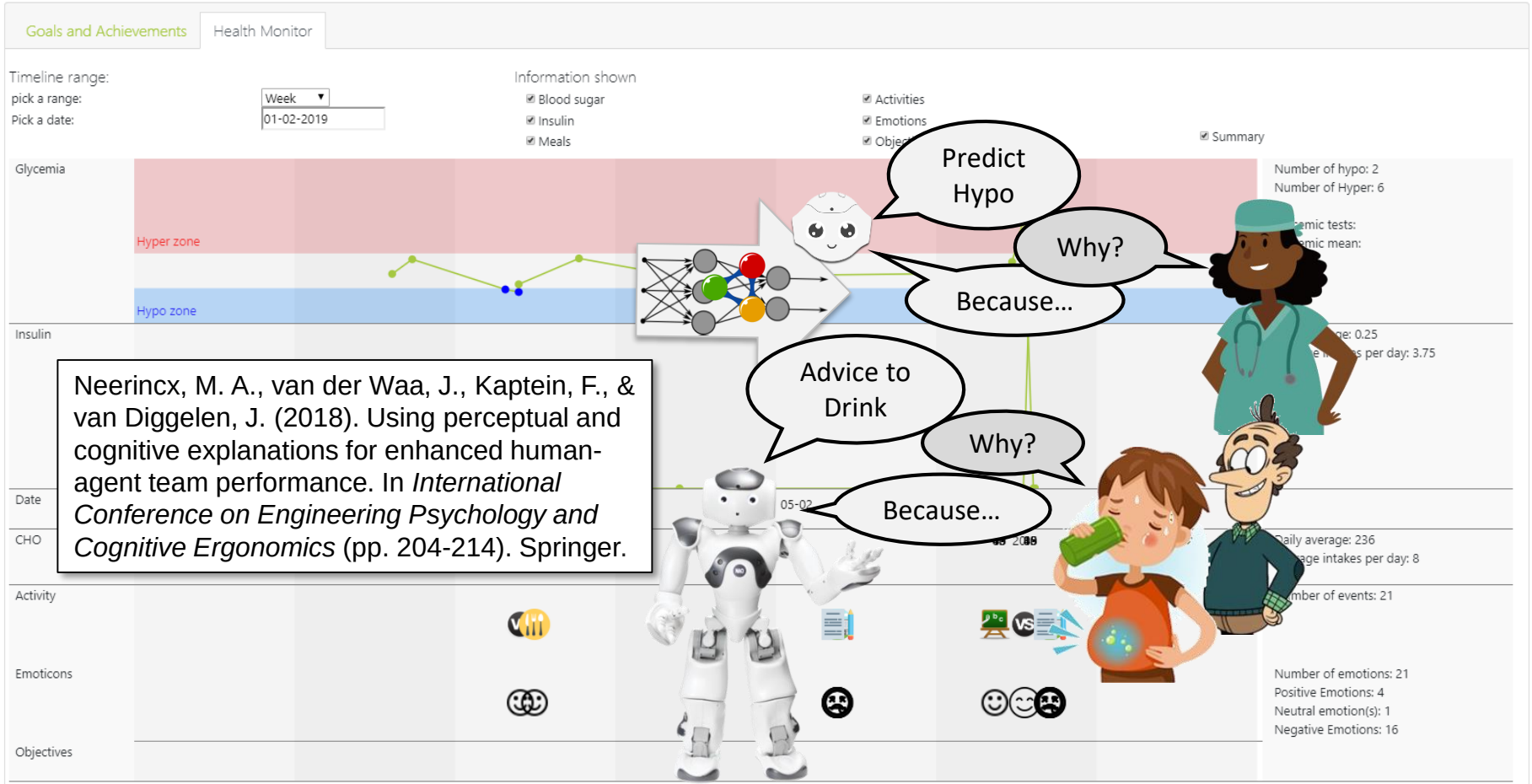
UPTAKE & LEARNING BY FEEDBACK

Direct Feedback:

- Informative
  - Corrective
  - Descriptive
  - Evaluative
  - Confirmatory
- Motivational
  - Encouragement
  - Remark
  - Mood matching
  - Praise



R&D CONTINUES, E.G. ON EXPLANATIONS

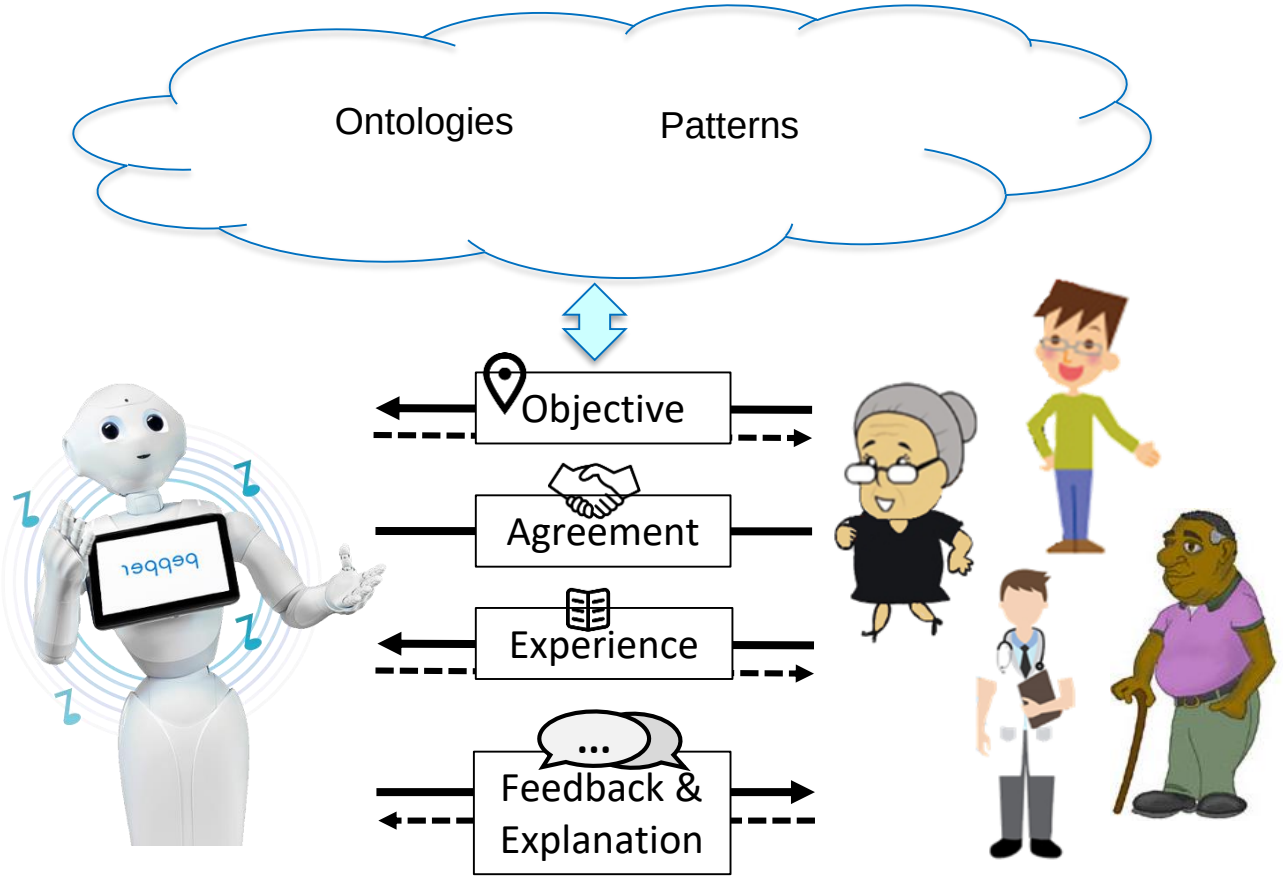


Neerincx, M. A., van der Waa, J., Kaptein, F., & van Diggelen, J. (2018). Using perceptual and cognitive explanations for enhanced human-agent team performance. In *International Conference on Engineering Psychology and Cognitive Ergonomics* (pp. 204-214). Springer.

HUMAN-AGENT PARTNERSHIPS IN ELDERLY CARE

Mark Neerincx

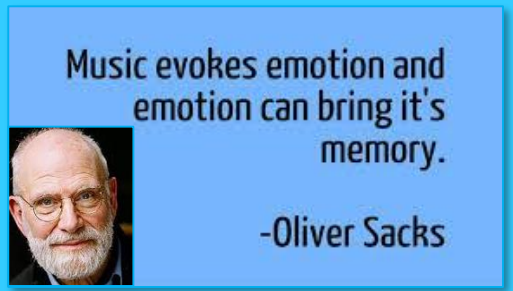
HUMAN-AGENT PARTNERSHIP

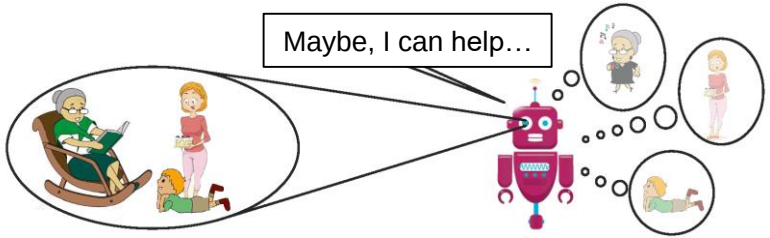


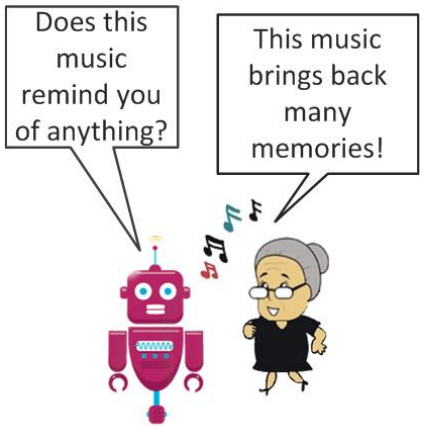
ROBOT-SUPPORTED ACTIVITIES

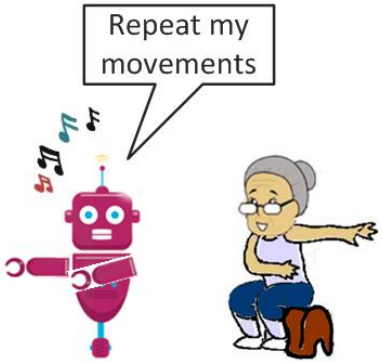
MUSIC-ENRICHED

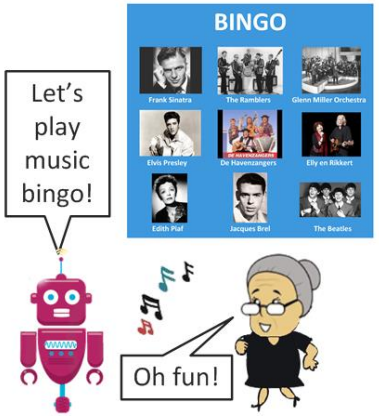
- Emotion
- Memory
- Behavior
- Connects people











https://rejam.tudelft.nl/

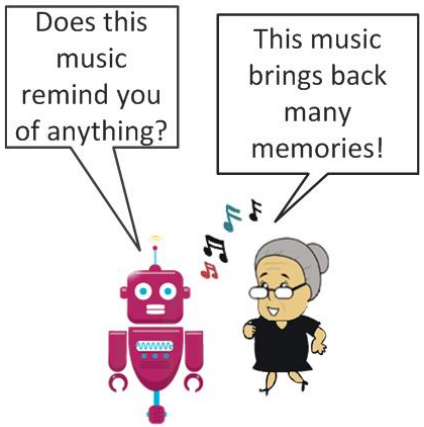
MUSIC-DRIVEN OR -ENRICHED ACTIVITIES

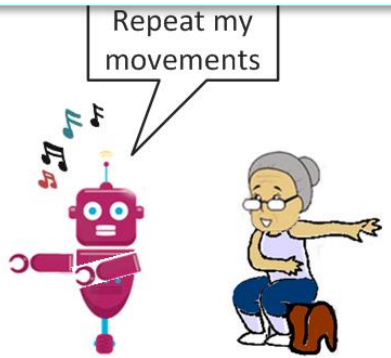
Evaluation:

- at living rooms in a meeting centre for PwD.
- 30 PwD, 8 activity coordinators
- 3 weekly 90-minute sessions

Result:

- Robot with music-related group activities stimulates the PwD socially, cognitively, affectively and physically.
- Particularly, the reminiscence activity was appreciated.





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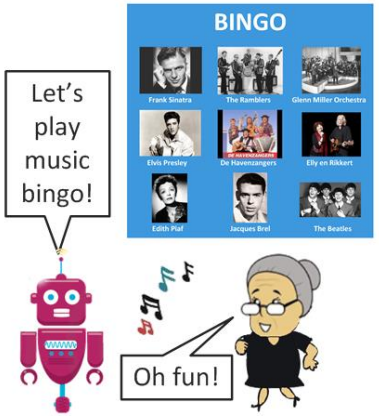
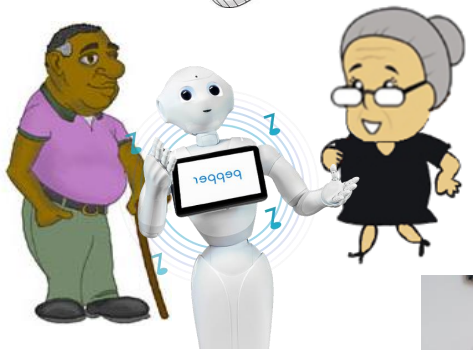


ROBOTIC PARTNER FOR PEOPLE WITH DEMENTIA

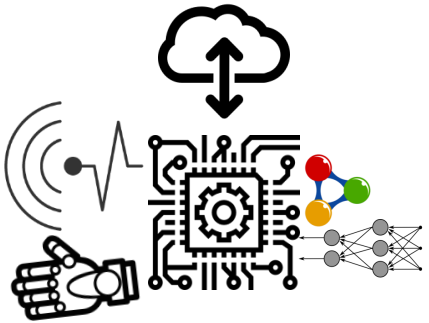


ReJAM: **R**obots engaging **e**lderly in **J**oint **A**ctivities with **M**usic (rejam.tudelft.nl)

- Peeters, M.M., Harbers, M., & Neerincx, M.A. (2016). Designing a personal music assistant that enhances the social, cognitive, and affective experiences of people with dementia. *Computers in Human Behavior*, *63*, 727-737.
- De Kok, R., Rothweiler, J., Scholten, L., van Zoest, M., Boumans, R., & Neerincx, M.A. (2018). Combining Social Robotics and Music as a Non-Medical Treatment for People with Dementia. In *27th IEEE International Symposium on Robot and Human Interactive Communication (RO-MAN)* (pp. 465-467).
- Neerincx, M.A., Peeters, M.M.M., Psychoula, I., Oertel, C. Kreynen, B., and (to appear). The Design and Evaluation of a Robotic e-Partner Engaging People with Dementia in Joint Activities with Music.
- Agres, K. R., et al. (2021). Music, Computing, and Health: A roadmap for the current and future roles of music technology for health care and well-being. *Music & Science*, *4*, 2059204321997709.

SO, ROBOTIC PARTNERS EVOLVE BY…

- Integrating technology…
  - *AI, Robotics, Conversational Agents, Sensing, VR, Cloud Computing, IoT, …*
- into situated (“blended”) care
  - *social, cognitive, affective and physical processes*



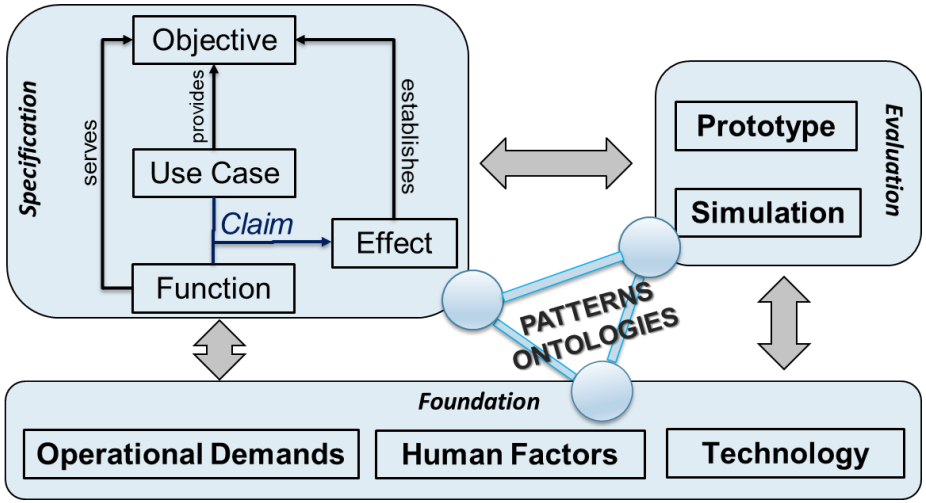
- with 4 core functions
  - Common situated objectives
  - Value-sensitive agreements
  - Shared knowledge base & experiences
  - Mutual uptake & learning by explanation & feedback

IN AN ITERATIVE DEVELOPMENT PROCESS

TNO innovation for life

Socio-Cognitive Engineering:

- Iterative incremental process
- Theory and empirical driven
- Combined operational (domain), human factors and technology perspective
- Stakeholder involvement in design and test activities
- Producing re-usable design specifications and implementations



THANKS FOR YOUR ATTENTION

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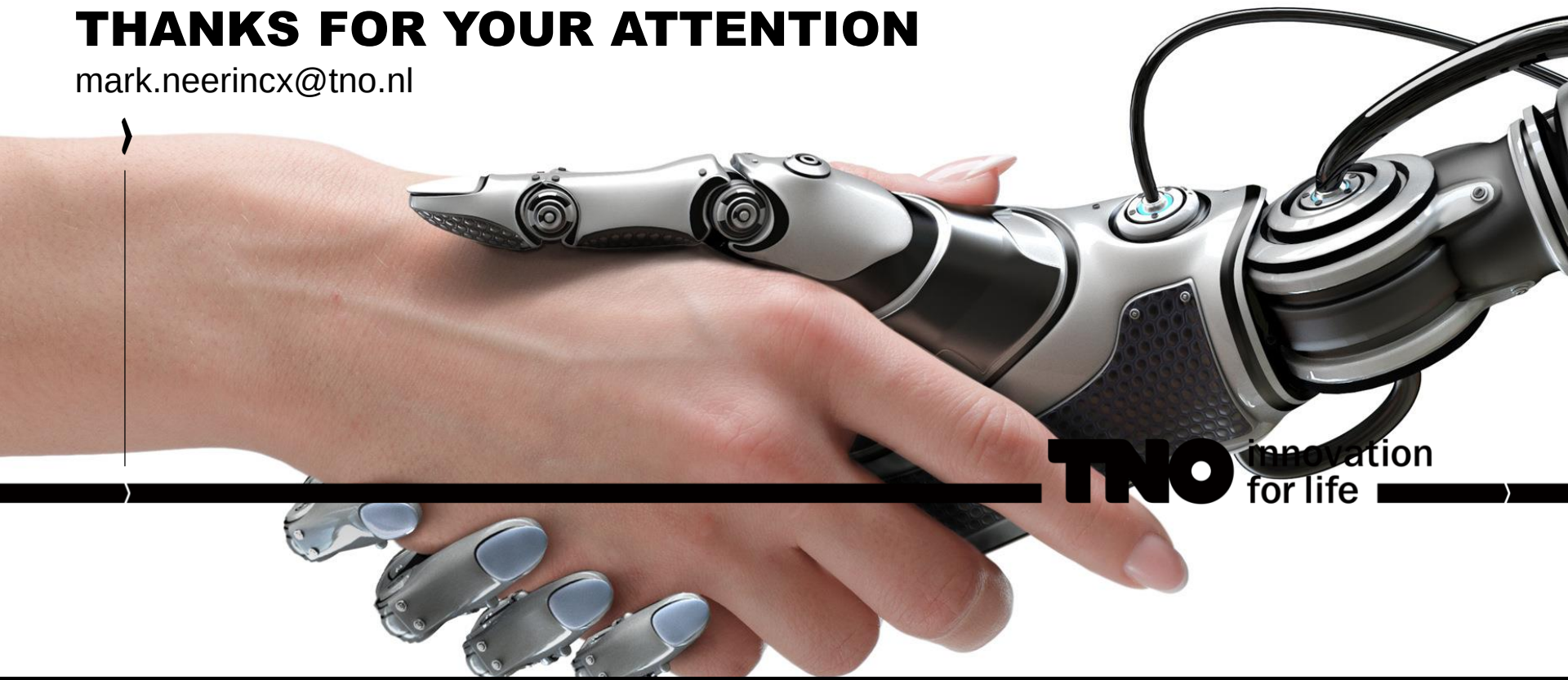

TNO innovation for life