COLLABORATIVE PLIABILITY MODEL

A Shared Conceptual Model to Make Cross-Disciplinary Collaboration Dynamics Meaningful to Mechanical Engineers

The Collaborative Pliability Model is a tool developed for mechanical engineers.

It explains processes in collaborations between disciplines using concepts from mechanical engineering. Its primary purpose is for mechanical engineers to learn about these processes using conceptual knowledge from their own discipline. As a result, the knowledge attained from this model can be ingrained with knowledge that is already familiar.

The model is developed as part of the Master Thesis in Mechanical Engineering and Science Communication of Jorik van Koppen.

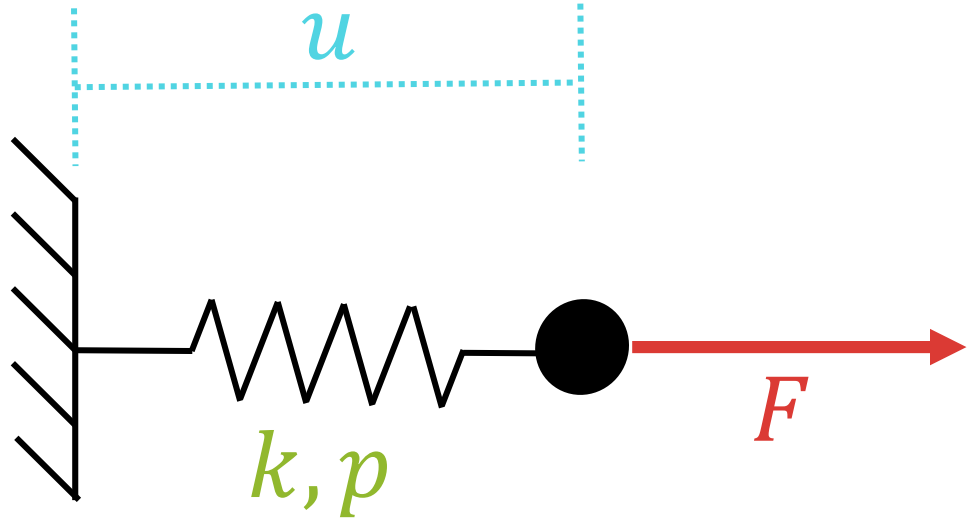
Mechanical Stiffness and Compliance

The **displacement of a linearly elastic spring u** changes in direct proportion to the **force F** acting on it. A key characteristic in defining the elasticity of the spring is the spring constant or **mechanical stiffness k**. The displacement of the spring is then the force F divided by the stiffness k:

$$u = \frac{F}{k}$$

A schematic representation of a spring is shown in Figure 1. While the force and displacement working on the system are **externally imposed**, the stiffness is an **internal system property**. If the force acting on the spring is twice as big, the displacement is also twice as big. Similarly, a spring that is twice as stiff causes a displacement that is twice as small if the same force is applied to it.

Mechanical compliance p is the opposite of mechanical stiffness k and is also a system property. A system being more stiff, so having a higher stiffness, is equivalent to a system being less compliant, so having a lower compliance. The displacement can also be written in terms of the force and compliance.



$$p = \frac{1}{k}$$

$$u = p \cdot F$$

Figure 1: Schematic of a spring with stiffness k or compliance p. The spring force F is exerted on the spring, causing a displacement u. The initial length of the spring is assumed to be zero.

Analogy with Collaborative Pliability

Synonyms for the word compliance are *complaisance*, *deference*, *elasticity*, *flexibility*, *pliability*, *springiness* and *tractability.* Antonyms are *noncomformity*, *refusal* and *resistance*.

The mechanical definition of compliance, as described on the previous page, can figuratively be compared to the definition of **collaborative pliability**, a concept stemming from collaboration sciences. Collaborative pliability describes a **professional's flexibility to move from personal concreteness to personal abstraction**. Personal concreteness is the space where conventional rules of problem-solving apply, whereas personal abstraction is the space where conventional reasoning and logic are taken out of context to solve problems that are not in the ordinary scope.

Whereas mechanical compliance (p) describes the system's flexibility to move in the physical space (u) when a force (F) is applied to it, pliability (p) describes a person's

flexibility to move from personal concreteness to abstraction (u) when incentives (F) are presented. In other words, a professional's movement to personal abstraction is dependent on a multiplication of two variables: incentives and the professional's pliability.

$$u = p \cdot F$$

$$\text{Movement to personal abstraction} = \text{Pliability} \cdot \text{Incentives}$$

In the mechanical as well as the social domain, **F and u are contextual, external factors** that are related to each other by the **system property p**. For a given instance of time, p has a set value that links u and F together. A more in depth description of the concepts 'movement to personal abstraction', 'pliability' and 'incentives' is given in the following sections.

Movement to Personal Abstraction (u)

Personal concreteness is the professional's concrete application of obtained knowledge. Familiar concepts, methods of problem-solving and disciplinary rules are used within this space. **Personal abstraction**, on the other hand, is an area containing (partially) unknown, new knowledge, methods of problem-solving or disciplinary rules. Creating logical connections in the area of personal abstraction is more difficult than within the area of concreteness.

The movement from personal concreteness to abstraction u is **not a black-to-white shift** and a concrete distinction between what is abstract and what is concrete cannot be made. Instead, some of the professional's knowledge can more concretely be evoked than other knowledge, **depending on the previous contact with and application of this knowledge**. For example, a college student will develop concrete knowledge during

the education program. As the curriculum progresses, knowledge, concepts and relations will become more concrete as the student gets more familiar with how theory can be applied.

Within a collaboration between professionals, be it disciplinary or cross-disciplinary, there is **always some exposure to a degree of disciplinary abstraction** for everyone involved. The incentives that are presented and pliability of the professionals determine up to what extent each professional displaces towards personal abstraction. If the displacements are sufficient, a point of intersection can be found. As a result, professionals can relate familiar knowledge to each other to communicate and share ideas. This intersection point is usually more abstract to one professional than to the other, depending on the previous experience of both professionals with the topic.

Incentives (F)

A movement is always initiated by an inducement. In the physical domain, the movement of the spring is initiated by a **force F** extending the spring. The compliance p relates this force to the displacement u. Likewise, a disciplinary displacement is initiated by an **incentive F** that triggers the professional to displace to personal abstraction. The pliability p relates this incentive to the resulting disciplinary displacement.

One incentive can trigger a displacement of multiple professionals n. It is an action that can cause **multiple reactions**:

$$\begin{bmatrix} u_1 \\ u_2 \\ \vdots \\ u_n \end{bmatrix} = \begin{bmatrix} p_1 \\ p_2 \\ \vdots \\ p_n \end{bmatrix} F$$

A distinction between **two types of incentives** is made: Internal and external incentives. An external incentive for one discipline can be an internal incentive for another discipline. In formula form, this distinction is not elucidated and both types of incentives are referred to as F.

Internal Incentives

Internal incentives are thoughts and actions emerging from professionals themselves. Examples of internal incentives are the **intrinsic willingness** to collaborate with another scientific team, the **personal collection of information** that leads to new insights or **conversations** that were conducted with a cross-disciplinary partner. Internal incentives are often the cause of **proactivity**.

While internal incentives and pliability are both concepts related to what is happening inside the professional, there is a fundamental difference between these two.

Incentives are always the reason that change is occurring. They are actions that induce movements to personal abstraction. Pliability, on the other hand, is merely a system property that translates the incentive to a shift towards personal abstraction. Pliability is a time-varying system property, whereas internal incentives are context-dependent initiators. Both are needed to realise a disciplinary displacement: An infinitely stiff spring will not move no matter how hard you tug on it, but if you do not pull on a spring it will never move, no matter how compliant the spring.

External Incentives

External incentives are induced by something other than the professional. They are the external forces causing the professional to move. Examples are **financial motives** imposed by the government, **investments** done by investors to develop a specific cross-disciplinary project or the **desire of collaboration partners** to work together.

Collaborative Pliability (p)

Collaborative pliability is the **system property** that determines the **magnitude of a displacement to personal abstraction as the result of an incentive**. An analogy is made with joint stiffness, which describes the human stiffness of a joint that changes as a result of external factors. Some models approximate the total value of joint stiffness as the sum of the different factors that contribute to stiffness changes. These factors are in reality not completely independent: Coupling takes place, which is the effect of stiffnesses mutually influencing one another. The same principle is used to describe the different factors influencing pliability. The effects of coupling are neglected and it is assumed that the contributions accountable for different parts of the stiffness can be summed linearly:

$$u = F(p_p + p_i + p_g + p_d)$$

In this equation, **personal pliability p_p** refers to pliability or pliability changes due to personal factors. **Interpersonal pliability p_i** refers to pliability or pliability changes due to interpersonal factors. **Group pliability p_g** is impacted by group factors and finally, **disciplinary pliability p_d** is impacted by disciplinary factors. One discipline is more pliable than the other, just like one team is more pliable than the other. Also, people's pliability may differ depending on who they are working together with. Finally, some individuals are more pliable than others.

Mind that this distinction does not mean that disciplinary pliability is the same for each professional of a discipline, group pliability is the same for everyone in the group and interpersonal pliability is a pliability changing equally for two collaborating partners. Instead, each pliability represents the contribution of disciplinary, group and interpersonal dynamics to the person's pliability. **These changes are different for every professional.**

Since one incentive can trigger a displacement of multiple professionals, this equation can be further expanded in the following form:

$$\begin{bmatrix} u_1 \\ u_2 \\ \vdots \\ u_n \end{bmatrix} = \begin{bmatrix} p_{1,p} + p_{1,i} + p_{1,g} + p_{1,d} \\ p_{2,p} + p_{2,i} + p_{2,g} + p_{2,d} \\ \vdots \\ p_{n,p} + p_{n,i} + p_{n,g} + p_{n,d} \end{bmatrix} F$$

with *n* the total number of professionals impacted by the incentive. In the technical domain, the stiffness of a spring can change due to factors like erosion, material fatigue or a nonlinear position dependency. In the social domain, pliability also **changes in time and it changes differently per person**. The following slides give examples of how each type of pliability is defined and how it can change.

Personal Pliability (p_p)

Personal pliability generally increases with experience in the long term. This is related to a conjunction of factors that can best be described as **collaborative readiness**. Moving towards the area of personal abstraction can go paired with discomfort, frustration and confusion. With experience, a professional develops expectation management that eases dealing with these effects.

Apart from these effects, all professionals have a '**baseline**' personal pliability depending on their characteristics. This baseline pliability can slowly increase or decrease as a function of time, depending on new experiences and changing worldviews.

There are also **swift, volatile processes** that change the personal pliability from day to day. However, the long-term pattern of these effects are more difficult to grasp.

Interpersonal Pliability (p_i)

Interpersonal pliability is relationship-based and focused around the pliability of collaborating with one other professional specifically. A professional's interpersonal pliability is different depending on the partner that he or she is collaborating with.

A reference point for interpersonal pliability is the **difference of worldviews** of two professionals. More like-minded professionals are more pliable to collaborate because like-mindedness gives the expectation that other ideas of the collaborating professional are generally also comparable to own ideas.

A more changeable but influential factor influencing interpersonal pliability is **trust**. Trust between two professionals is something comprehensive that cannot easily be described, but it can have a big impact on how willing two professionals are to collaborate. It is something that can improve quickly over time, but also deteriorate swiftly.

Group Pliability (p_g)

Group pliability is the professional's pliability due to dynamics at the group level. From a policy perspective, group pliability is the easiest to change and often the target of policy interventions. Group pliability does not change equally for every professional part of a group since policy decisions affect each professional differently.

A factor influencing group pliability is the **leadership** of a team. A leader can actively take a facilitating role within a team to streamline the collaboration process, which can yield pliability commitments. Other factors that indirectly have an impact on the team members' pliability are the **outcome interdependence** between the team members and the team size. With interdependent goals determined within a team, working together is more of a necessity and team members will be more inclined to pliable thinking. While **team size** likely impacts the group pliability, it can have mixed effects on the group pliability of the team members.

Disciplinary Pliability (p_d)

Finally, disciplinary pliability is the effect of disciplinary dynamics on the professional's pliability. The dynamics at the disciplinary level change slowly if they change at all. It is difficult to modify them, but their importance cannot be neglected.

Disciplinary aspects like the discipline's **history**, the amount of **codification** and **prominent models and artifacts** play a big role in how things are organised and looked at within a discipline. The amount of codification means that there is less freedom to apply disciplinary knowledge pliably. Hence, professionals from disciplines that are more codified will have lower disciplinary pliability.

A more changeable factor influencing disciplinary pliability is what happens on the **socio-political level** within a discipline. Socio-political dynamics can change the need or openness to other disciplinary worldviews, in turn impacting the disciplinary pliability.

Schematic Representation

Personal concreteness can be represented in a 2D plane using a **different shape for every person**, representing the variety in perceptions of personal concreteness. Some examples are shown in Figure 2. The area inside the shape is the personal area of concreteness. The area outside of this shape is defined as personal abstraction. Even within what is currently modelled as an area of concreteness, a certain degree of pliability is often required to map knowledge that is more concrete to an area that

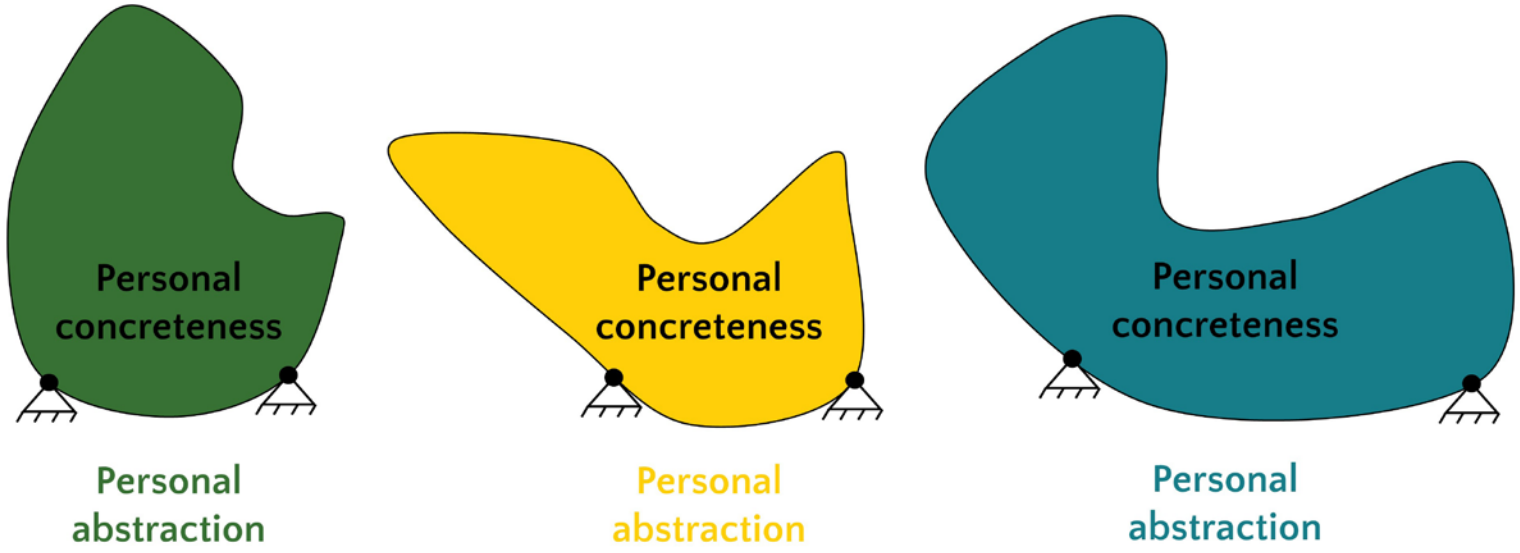


Figure 2: Schematic of the difference in shapes in personal concreteness between different individuals. The two ground symbols at the borders of each shape indicate that the shapes themselves do not move. To avoid having cumbersome figures, these symbols are not drawn in the upcoming figures.

is relatively abstract but still quite concrete. The **hard border at the edges of each area is actually a gradient** from more concrete in the centre towards more abstract at the edges.

Depending on the context of problem-solving and the collaboration partners, professionals can evoke knowledge from their area of personal concreteness **with little effort**. However, when concepts in a collaboration become more abstract, professionals are compelled to conceptualise knowledge in the area of personal abstraction to find a point of intersection with the collaboration partners. This is where **a degree of pliability is required**: Depending on the pliability of the professionals they will be able to conceptualise knowledge that is further or less far in the area of personal abstraction.

The left shape in Figure 3 represents a situation where the professional conceptualises knowledge in his or her area of personal concreteness. No (or actually, little) incentives are required for the professional to understand concepts, methods and logic inside this area.

The middle and right shapes in Figure 3 represent two instances where a professional is exposed to incentives to move towards personal abstraction. The movement from personal concreteness to abstraction can schematically be represented **using the spring analogy**. The product of incentives and pliability of the professional determines how abstract the knowledge is that the professional can conceptualise.

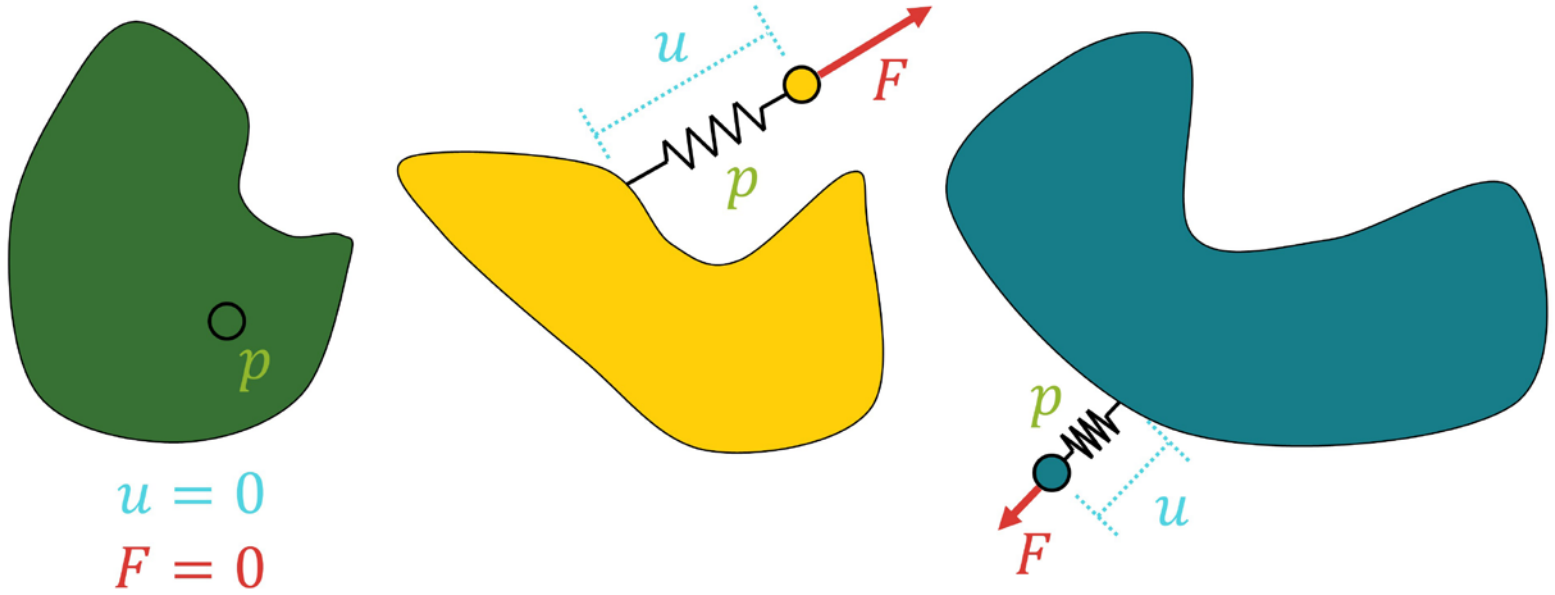


Figure 3: Schematic of how individuals can evoke knowledge with respect to their personal concreteness and abstraction, making use of the spring analogy. The circles represent the knowledge that the professional is evoking. In each situation, incentives F present themselves and the person's movement to personal abstraction u can be observed. The magnitude of the movement is dependent on the professional's pliability p.

The areas of personal concreteness are **not static:** Whenever professionals try to conceptualise knowledge outside of their conventional areas of concreteness, the concepts that were abstract at first start to make more sense. By visiting an area of abstraction repeatedly and frequently, the conceptualisation of this area becomes more concrete as visualised in Figure 4.

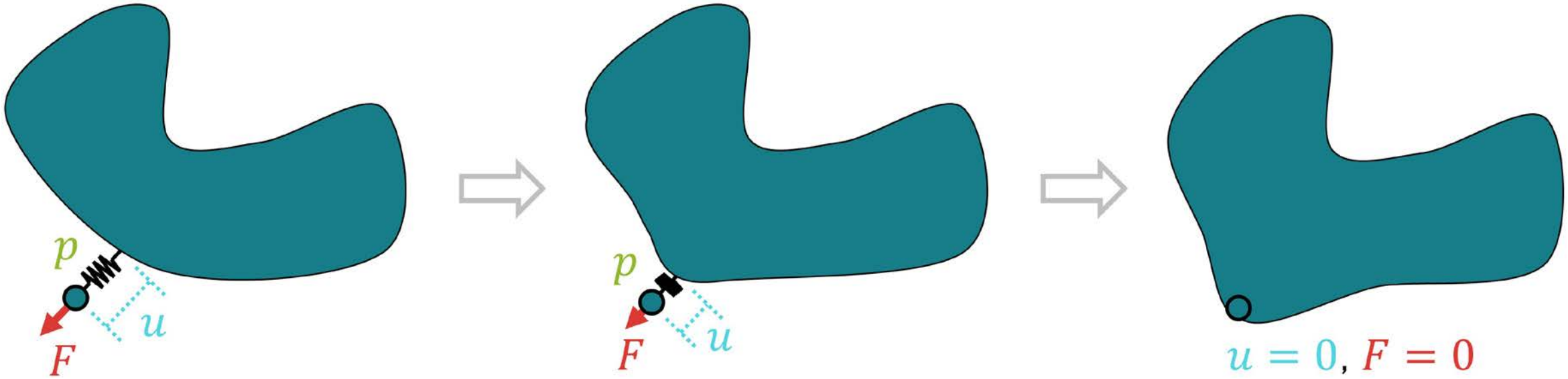


Figure 4: Schematic showing how the areas of personal concreteness are constantly changing. By evoking knowledge in the area of disciplinary abstraction, knowledge in this area becomes more concrete and the size of the area of personal concreteness increases.

Levels of Cross-Disciplinary Integration

Now that the fundamentals of the model are covered, the differences between disciplinarity, multidisciplinarity, interdisciplinarity and transdisciplinarity can be clarified.

Disciplinary Collaboration

In a disciplinary collaboration, the professionals involved in the collaboration have **overlapping areas of personal concreteness**, see Figure 5. This is often because they have similar educational backgrounds or experiences. They are familiar with working with the same concepts, theories and methods to tackle problem-solving and know about the bottlenecks and struggles when solving a problem within this area of concreteness.

Because all professionals have their specialisations, fields of interest and knowledge, there are still parts where not all the areas of concreteness overlap, or none overlap at

all. Still, **relatively little pliability is needed** for the professionals to find an area of intersection and mutual concreteness. Making such a collaboration succeed is easiest compared to the other collaboration types.

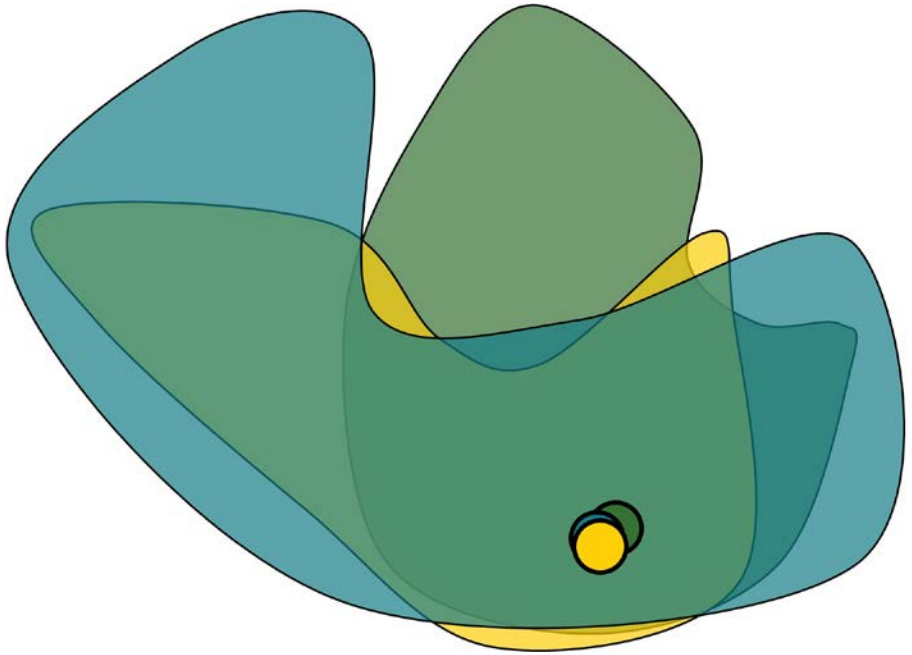


Figure 5: Example of the personal areas of concreteness within a disciplinary collaboration. The professionals have overlapping areas of concreteness and little pliability is required to conceptualise shared knowledge.

Multidisciplinary Collaboration

In a multidisciplinary collaboration, **clusters of professionals** work together that have shared areas of concreteness within the cluster, whereas there is **little to no overlap between the areas of concreteness of different clusters**, see Figure 6. One cluster can be seen as a discipline or a team that has prior experience working together.

Again, the local areas of concreteness are relatively easy to find, but communicating ideas and concepts from one cluster to another is more difficult because **ideas are not shared with a common conceptual basis**. As a result, teams work together in a relatively isolated fashion and strip ideas from the majority of their disciplinary context when communicating, anticipating that they are more meaningful by neglecting discipline-specific details and considerations that go into problem-solving.

Multidisciplinary collaborations can be seen as clusters of disciplinary collaborations, in which little pliability is needed to communicate effectively. Because within the transfer of knowledge between clusters problems are stripped of most of their

disciplinary complexity, less pliability is needed as compared to a situation where the full scope of complexity is shared with the other cluster. Knowledge is rarely conceptualised at a point of intersection by professionals from different clusters.

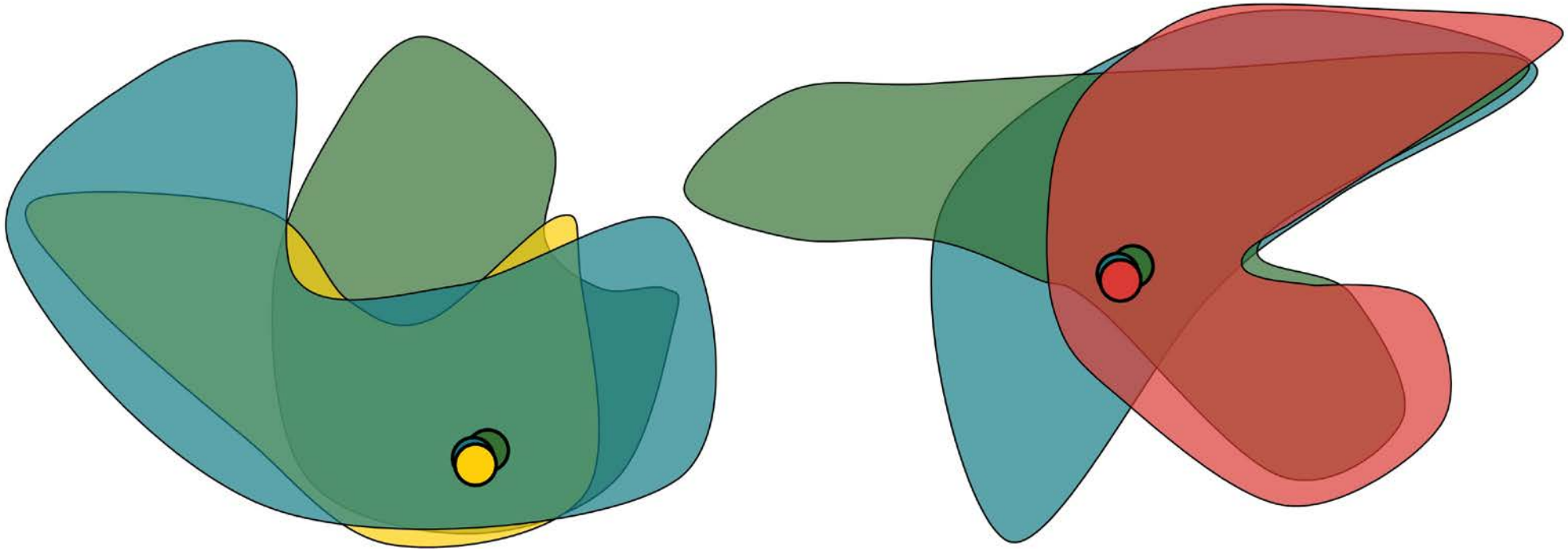


Figure 6: Example of the personal areas of concreteness within a multidisciplinary collaboration. Professionals conceptualise shared knowledge in clusters, but a shared conceptualisation of knowledge does not occur within the whole team.

Interdisciplinary Collaboration

Within an interdisciplinary collaboration, professionals from different disciplines move **away from their areas of personal concreteness towards abstraction**, see Figure 7. Somewhere within this space, disciplines find each other to create solutions containing logic and concepts from both disciplines. The point of intersection is closer to the area of concreteness for some professionals than for others, and some professionals need more pliability to understand the logic within this area of intersection than others. The point of intersection can even be within the area of concreteness of some professionals.

The figure shows that professionals now need to **c**onceptualise knowledge in their domains of personal abstraction to find common ground. To do this, **professionals need a degree of pliability** to collaborate effectively. Ideas, concepts and problems that are shared within this area of abstraction constantly need to be mirrored back to the area of concreteness of the professional, which takes considerable effort and may take some time to process. Once this process is initiated, a bridge for knowledge

transferring is established between two different conceptual models that are not necessarily related to one another.

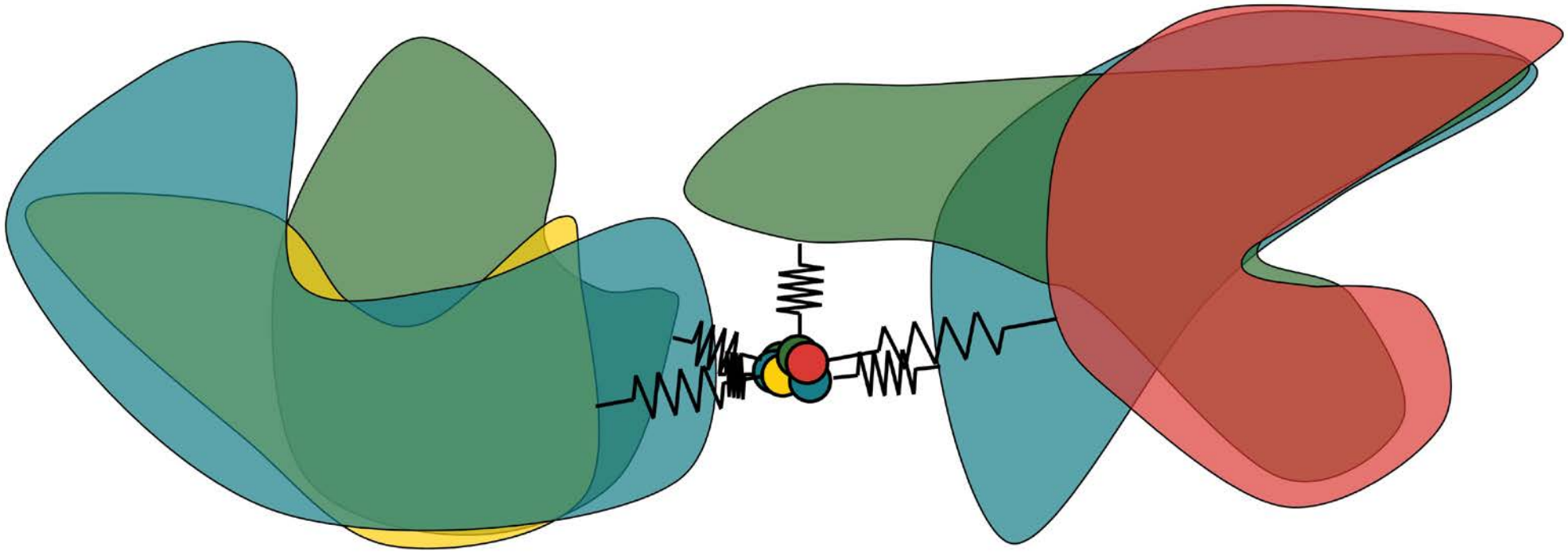


Figure 7: Example of the personal areas of concreteness within an interdisciplinary collaboration. The professionals conceptualise knowledge outside of their personal areas of concreteness to find an area of intersection. Doing so requires incentives and a degree of collaborative pliability.

Transdisciplinary Collaboration

The final and most integrated form of collaborating is a transdisciplinary collaboration. When shared knowledge is **repeatedly and frequently conceptualised in the areas of personal abstraction**, professionals will perceive this knowledge as less abstract as time progresses. Eventually, their fields of personal concreteness are expanded in the direction of the newly developed knowledge as was explained in Figure 4. The result is shown in Figure 8. A new area of concreteness is developed that contains methods, concepts and tools from multiple disciplines that participated in the collaboration.

Creating a truly transdisciplinary collaboration needs professionals to work together in an integrated and interwoven manner. A great deal of pliability is required to constantly re-evaluate collaboration problems and mirror these to knowledge within personal concreteness. In the initial stage of a transdisciplinary collaboration, where knowledge integration still has to unfold, the areas of personal concreteness resemble the ones sketched in Figure 7. Repeatedly scouring through the area of personal abstraction can be a resourceful process. However, with due time, the mental models

of the professionals are permanently broadened, **creating new knowledge** that the professional can comfortably use to tackle problems as shown in Figure 8.

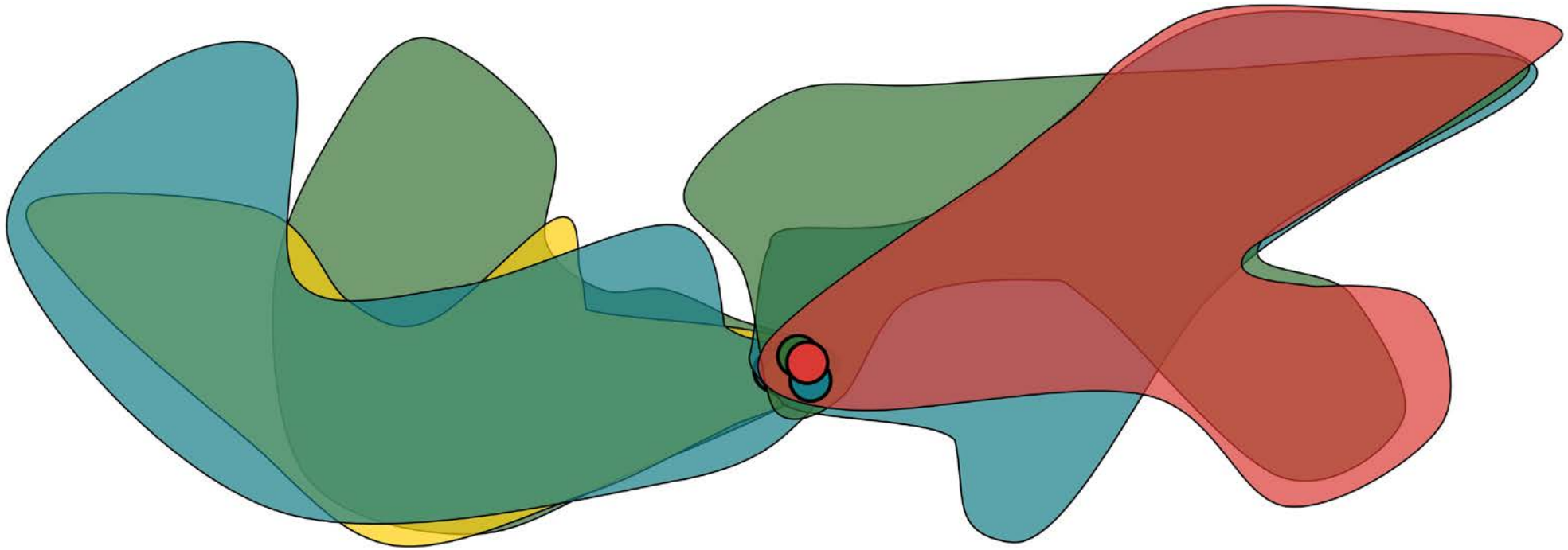


Figure 8: Example of the personal areas of concreteness within a transdisciplinary collaboration. The professionals intensively sought to find common ground by repeatedly trying to conceptualise knowledge in a domain abstract to them. As a result, their areas of personal concreteness have morphed and a shared area of concreteness has been developed.

Collaborative Pliability Model

Formulas

$$u = p \cdot F$$

$$\begin{bmatrix} u_1 \\ u_2 \\ \vdots \\ u_n \end{bmatrix} = \begin{bmatrix} p_{p,1} + p_{i,1} + p_{g,1} + p_{d,1} \\ p_{p,2} + p_{i,2} + p_{g,2} + p_{d,2} \\ \vdots \\ p_{p,n} + p_{i,n} + p_{g,n} + p_{d,n} \end{bmatrix} F$$

p : Pliability

u : Displacement from personal concreteness to abstraction

F : Incentives

Pliability Types

Personal Pliability p_p

- Influenced by
  - General mood
  - Collaborative readiness
  - Motives, global innovativeness

Interpersonal Pliability p_i

- Influenced by
  - Overlap of world views
  - Trust and familiarity

Group Pliability p_g

- Influenced by
  - Team size
  - Outcome interdependence
  - Leadership

Disciplinary Pliability p_d

- Influenced by
  - Codification
  - Models and artifacts
  - History
  - Larger socio-political realities

Collaboration Types

Disciplinary	Multidisciplinary	Interdisciplinary	Transdisciplinary