Cognitive Science Approach to Achieve SDGs

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***Abstract*—The UN report, "The Future is Now: Science for Achieving Sustainable Development," expressed expectations for contributions from cognitive science for the achievement of the Sustainable Development Goals (SDGs). This is because achievement of the SDGs can be regarded as an extension of problem-solving activities in individuals' daily behavior choices. However, as categorized in Newell's "time scale of human action," the SDGs belong to the SOCIAL BAND, while individuals' daily problem-solving belongs to the COGNITIVE BAND, which makes it difficult to construct predictive models. In other words, it is impossible to define a well-defined problem space that spans between the non-linearly connected BANDs. As an alternative approach, this paper proposes an adapted version of the Cognitive Chrono-Ethnography (CCE), a study methodology integrating cognitive science and ethnography, for understanding individuals' daily behavior and specifying their action selection activities that would eventually lead to the achievement of some of the SDGs.**

Keywords–Sustainable Development Goals (SDGs); Cognitive Chrono-Ethnography (CCE); real world problem-solving; adaptive problem-solving; happiness goals.

I. Introduction

The Sustainable Development Goals (SDGs) are a blueprint for achieving a better, more sustainable future for all. They are aimed at addressing the global challenges we face, including those related to poverty, inequality, climate change, environmental degradation, peace, and justice. Under the SDGs, 17 interconnected goals, and 169 targets under these goals, have been defined. For instance, "Goal 3: Ensure healthy lives, and promote well-being for all at all ages" is associated with 13 targets, such as "3.9 By 2030, substantially reduce the number of deaths and illnesses from hazardous chemicals and air, water and soil pollution and contamination." In the report entitled "The Future is Now: Science for Achieving Sustainable Development," which is the first quadrennial Global Sustainable Development Report prepared by an independent group of scientists [1], the cognitive capacity required for sustainable development choices has been explained as follows:

> During the long period of human evolution, humans have overcome multiple complex challenges, and remained highly adaptive. There is therefore reason to hope that we will also overcome the current challenges to sustainability that are faced on a societal – indeed global – scale. Evolutionary adaptation is most often based on tangible experiences, short-term outcomes and relatively straightforward theories of change. Several aspects of the transformation towards sustainability can be different.
> $(\cdots)$
> Changing behaviours towards evolutionary adaptation in such a context can therefore be different from other contexts in which humanity has had to deal with society-wide challenges. Individuals will play a pivotal role in driving the necessary transformations. Understanding how people – as consumers and engaged citizens – make choices and decisions in that regard can help to further motivate such action [2]. Cognitive science, psychology, behavioural economics, neurobiology and brain research can provide important insights in that regard [3]. They might indicate, for example, what is going on in our brains when we hear science-based information about sustainability challenges, and consequently make decisions and choices.

Thus, the United Nations (UN) report [1] has clearly outlined the need for contributions from cognitive science. At first sight, the kinds of activities involved in achieving any of the SDGs may be considered as problem-solving activities; hence, the knowledge concerning problem-solving that has been accumulated in cognitive science should prove to be of due relevance in achieving SDGs. However, as shown in the next section, the band structure of human action, [4, page 122, Fig. 3-3] when incorporated into the problem space, which includes both SDGs and real world problem-solving, makes the application of predictive models, such as production systems (e.g., Adaptive Control of Thought - Rational (ACT-R) cognitive architecture [5][6], and Soar [7]), and the Goals, Operators, Methods and Selection rules (GOMS) approach to user modeling [8] less useful than it would be under situations tailored to bolster the effectiveness of these prediction systems.

Accordingly, the rest of this paper explores the issue of appropriate treatment and utilization of cognitive science for contributing to the achievement of SDGs. Section II describes how problem-solving activities are related to achieving SDGs. Section III describes how the Cognitive Chrono-Ethnography (CCE) can be applied for specifying individuals' problem solving activities that would eventually lead to the achievement of some of the SDGs. The acknowledgement and conclusions are provided at the end.

II. Problem Solving for Achieving the SDGs

Efforts to achieve the SDGs ultimately translate into individual human efforts. In some cases, an individual may seek to achieve any of the SDGs *directly*, while in other cases, he or she may seek to achieve any of the SDGs *indirectly*, through activities within the organization or the community to which the individual belongs. In either case, such an activity on the part of an individual can be considered as an activity oriented toward achieving one or more SDGs.

A. Societal SDGs vs. Individual Level Goals

Activities to achieve any of the SDGs have to be implemented as problem-solving activities conducted in the real world context, which is called "real world problem-solving" [9]. However, as pointed out in the UN report [1], it would be difficult for a majority of people to concretely envisage the situations wherein any of the SDGs can be achieved, and ascertain the relevance of using real-world problem solving on an individual level to achieve these goals. An example from the UN report is as follows:

> Carbon dioxide emissions, for example, are not seen, smelled or directly experienced as harmful, and their negative impacts will occur relatively far into the future, while they are often associated in the present with behaviours that are immediately useful or pleasurable. Their likely impacts and delayed risks are inferred from science-based models rather than immediate individual experience, although that may currently be changing.

This difficulty can be easily understood by considering Newell's time scale of human action [4, page 122, Fig. 3-3]. As shown in Table I, it identifies non-linearly connected four bands: SOCIAL, RATIONAL, COGNITIVE, and BIOLOGICAL. The claim that human action should be structured in terms of these four discrete bands, suggests that it should be possible to build predictive and explanatory models for activities that happen within a single band, and at the same time, it should be impossible, or inappropriate, to build predictive models that include activities that happen in multiple bands with inter-band interactions. The impossibility of constructing predictive models for inter-band activities comes from the existence of non-linear inter-band connections, which would also make the predictive and/or explanatory models non-linear. Even if a model is deterministic, it will suffer from Sensitive Dependence on Initial Condition (SEDIC), a primary feature of such a non-linear system, and consequently, become unpredictable.

As also shown in Table I, the SDGs exist in the SOCIAL BAND, whereas the goals for real world problem-solving exist in the COGNITIVE BAND or RATIONAL BAND. Problem solving activities that are conducted in one band should not be linearly connected to those activities conducted in a different band because there are gaps between different bands. Activities within a band, however, can be linearly connected to each other, and it is possible to perform problem-solving activities in a well-defined problem space, if the problem-solver has sufficient knowledge to represent the problem space. However, it is impossible for a problem-solver to represent a problem space as a well-defined one if goals exist in different bands, i.e., some goals are in the SOCIAL BAND and others in the COGNITIVE BAND, because of the unpredictable nature of such a non-linear system.

Problem-solvers can identify a top-level goal that belongs to any of the SDGs and lower level goals that belong to the BAND where their real-world problem-solving activities are carried out. These lower level goals would effectively contribute as sub- or sub-sub- goals, and so on, in the entire hierarchical goal structure. However, the problem thus constructed, should have the features of ill-defined problems

TABLE I. NEWELL'S TIME SCALE OF HUMAN ACTION. (ADAPTED FROM NEWELL [4, PAGE 122, FIG. 3-3]).

Scale (sec)	Time Units	System	World (Theory)
10^7	months		
10^6	weeks		SOCIAL
10^5	days		BAND
10^4	hours	Task	
10^3	10min	Task	RATIONAL
10^2	minutes	Task	BAND
10^1	10sec	Unit Task	
10^0	1sec	Operations	COGNITIVE
10^{-1}	100ms	Deliberate Act	BAND
10^{-2}	10ms	Neural Circuit	
10^{-3}	1ms	Neuron	BIOLOGICAL
10^{-4}	100μsec	Organelle	BAND

because even if the state the problem-solver is currently in is well-specified, and the moves associated with the current state toward the states belonging to a different band are defined, i.e., the what and how to do is clearly specified, it is not possible to anticipate the result of the execution of the selected move due to the non-linear relationships between the goals in the different bands.

B. Real World Problem-Solving

Any activities that eventually lead to the achievement of any of the SDGs have to be implemented as problem solving activities that are conducted in the real-world context [9]. Skills necessary for performing these problem solving activities can be acquired through adaptive problem-solving activities [10] that have been studied thoroughly in an effort to implement the second cycle of the Programme for the International Assessment of Adult Competencies (PIAAC) survey. Note that the PIAAC is a program focusing on the assessment and analysis of adult skills. The major survey conducted as a part of PIAAC is the Survey of Adult Skills. This survey measures adults' proficiency in key information-processing skills – literacy, numeracy, and problem solving – and gathers information and data on how adults use their skills at home, at work, and in the wider community. This international survey is conducted in over 40 countries/economies, and measures the key cognitive and workplace skills needed for individuals to participate in society, and for economies to prosper.

A problem-solving task requires a problem solver to execute appropriate Perceptual-Cognitive-Motor (PCM) processes that are expected to be effective for accomplishing that task. Figure 1 illustrates how problem-solving activities happen at the interface between tasks and PCM processes. They could become diverse depending on the nature of the tasks, and how people carry out the PCM processes. External tasks impose time constraints on people's problem-solving activities, and people's PCM processes are carried out under the limitations (or possible ranges) of their specific PCM capabilities.

In general, individuals show a mixture of conscious and unconscious processes depending on the situation. Individuals' behavior is not always in alignment with their intentions residing in the RATIONAL BAND and the higher COGNI-

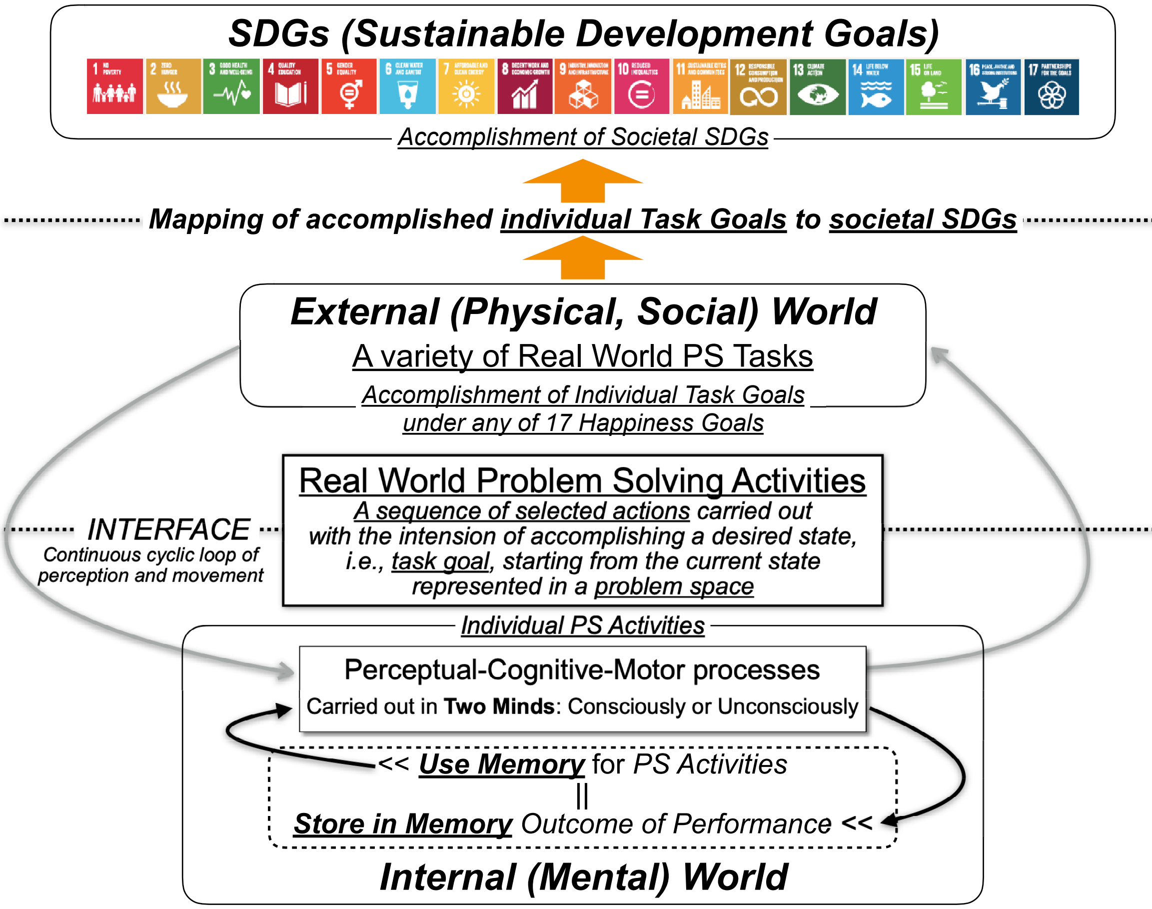

Figure 1. Accomplishing SDGs through individual real world problem solving activities for accomplishing individual task goals under happiness goals.

TIVE BAND, but is often carried out as activities in the lower COGNITIVE BAND at the order of hundreds of milli seconds. The former corresponds to System 2, and the latter to System 1. Kahneman [11][12] calls "System 1 and System 2" Two Minds, and describes System 1 as fast, automatic, and highly susceptible to environmental influences; and System 2 as slow-processing, reflective, and taking into account explicit goals and intentions. In this way, problem-solving activities are necessarily adaptive to the tasks people have to deal with. Adaptation is carried out within the range of PCM capabilities. As pointed out by Greiff et al. [10], "Adaptive Problem Solving" skill is one of the critical competencies people must have in order to achieve well-being in the contemporary multi-valued, networked, diverse, and heterogeneous society.

The interactions between the tasks that people encounter, and the PCM processes that people carry out to accomplish those tasks have a significant influence on people's development of problem-solving abilities. Therefore, people's past experiences significantly affect the actual action sequences for solving problems that are observed when some tasks to be performed are given to them. The bottom part of Figure 1 illustrates the relationships between real world problem-solving tasks and an individual's activities for accomplishing the goals. There are cognitive architectures available in the cognitive science society that are capable of simulating individuals' real world problem-solving activities (e.g., ACT-R [5][6], Soar [4], Model Human Processor with Realtime Constraints (MHP/RT) [13][14][15] , and so on).

C. Individual Level Achievement of SDGs

In some cases, individual activities performed in the COGNITIVE BAND or the RATIONAL BAND ultimately lead to the achievement of the SDGs belonging to the SOCIAL BAND. Banerjee et al. [17] reported such a case. They ran two Randomized Controlled Trials. Note that a Randomized Controlled Trial (RCT) is an experimental form of impact evaluation in which the population receiving the program or policy intervention is chosen at random from the eligible populations, and a control group is chosen at random from the same eligible populations. This method tests the extent to which specific, planned impacts are being achieved. The distinguishing feature of an RCT is the random assignment of units (e.g., people, schools, or villages) to the intervention or control groups. One of its strengths is that it provides a very powerful response to questions of causality, helping evaluators and program implementers ensure that the achieved outcome is a result of only the intervention, and not anything else.

Banerjee et al. [17] utilized this method and showed that vital information regarding vaccination was spread by using people who were considered gossips as information sources,

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TABLE II. HAPPINESS GOALS [16] AND THEIR RELATION TO SOCIAL LAYERS. +'S DENOTE THE DEGREE OF RELEVANCE OF EACH GOAL TO EACH LAYER, I.E., INDIVIDUAL, COMMUNITY, AND SOCIAL SYSTEM, RESPECTIVELY. +++: MOST RELEVANT, ++: MODERATELY RELEVANT, AND +: WEAKLY RELEVANT.

			Social Layers		
	Name of Happiness	Types	Individual layer	Community layer	Social system layer
1	Target Happiness	The Achiever	+++	+++	+++
2	Competitive Happiness	The Winner		+++	+++
3	Cooperative Happiness	The Helper		+++	+++
4	Genetic Happiness	The Relative	+++	+++	
5	Sensual Happiness	The Hedonist	+++	+++	
6	Cerebral Happiness	The Intellectual	+++	+++	++
7	Rhythmic Happiness	The Dancer	+++	+++	
8	Painful Happiness	The Masochist	+++		
9	Dangerous Happiness	The Risk-taker	+++	++	+
10	Selective Happiness	The Hysteric	+++	++	
11	Tranquil Happiness	The Mediator	+++		
12	Devout Happiness	The Believer		+++	++
13	Negative Happiness	The Suffer	+++	++	
14	Chemical Happiness	The Drug-taker	+++		
15	Fantasy Happiness	The Day-dreamer	+++		
16	Comic Happiness	The Laugher	+++	+++	
17	Accidental Happiness	The Fortunate	+++	+++	+++

and it eventually led to an increase in the vaccination rate. They proposed a research framework that can handle information propagation in situations where individuals cannot grasp the network structure through which information propagates. For their work, they received the Nobel Prize in Economics in 2019. In their study, the RCT method was used for verifying whether gossips, who had no knowledge about the structure of the information network, and had been nominated by people in the area, really worked toward spreading information. However, what the gossips did could be re-interpreted from the viewpoint of problem-solving activities as follows:

> The gossips did not necessarily work toward achieving any of the SDGs but their efforts for the fulfillment of their personal goals – that were likely to belong to the COGNITIVE BAND – led to the achievement of Goal 3 of the SDGs, "Good health and well-being for people" as a by-product.

Similar mechanisms could be implemented by using the concept of "nudge" in behavioral economics, which is any aspect of the choice architecture that alters people's behavior in a predictable way without forbidding any options or significantly changing their economic incentives [18][19]. In situations where the local decisions made in the COGNITIVE BAND do not take into consideration the consequences of the SOCIAL BAND (bounded rationality), actions are selected based on the principle of satisficing [20]. Currently, the coronavirus disease 2019 crisis requires large-scale behavior change. Bavel et al. [21, page 463] point out in their paper entitled "Using social and behavioural science to support COVID-19 pandemic response" that "nudges and normative information can be an alternative to more coercive means of behaviour change or used to complement regulatory, legal and other imposed policies when widespread changes must occur rapidly."

D. Problem Solving for Achieving Happiness Goals

Real world problem-solving is carried out within the COGNITIVE BAND. The actions taken by the gossips to spread information in the study by Banerjee et al. [17] can be understood using the PCM and memory processes, as depicted in Figure 1, by simulating their activities based on appropriate cognitive architectures. But what were the actual behavioral goals the gossips pursued?

It would be reasonable to assume that the goal of the gossips in their real world problem-solving is likely to have been providing useful information to their listeners. Morris [16] has characterized such goals as happiness goals and has listed 17 of them. The left portion of Table II shows these goals, including such goals as "the inherent happiness that comes with the love of a child," "the competitive happiness of triumphing over your opponents," "the sensual happiness of the hedonist," and so on.

Kitajima et al. [22] proposed the "Maximum Satisfaction Architecture (MSA)." MSA consists of three parts: 1) human brain characterized by System 1 and System 2; 2) society consisting of the three layers of Individual, Community, and Social system; and 3) happiness goals. MSA assumes that the human brain pursues one of the 17 happiness goals defined by Morris [16] at every moment, and switches to another goal when appropriate, by evaluating the current circumstances. Each of the happiness goals is associated with one or multiple layers of society. These layers have evolved from the history of human beings. Each layer is associated with its own value reflecting historical development, and thus, it relates to different sets of happiness goals.

The right portion of Table II shows tentative assignments of the degree of relevance of each goal to each layer. The middle portion of Figure 1 suggests that any real world problem-solving activities for achieving specific task goals would be conducted by individual persons in the pursuit of any of the 17 happiness goals in the social layers suggested in the right portion of Table II. The happiness goals would define a value structure of the problem-solver when he or she makes decisions by running the PCM and memory processes under specific circumstances while selecting his or her next actions. As such,

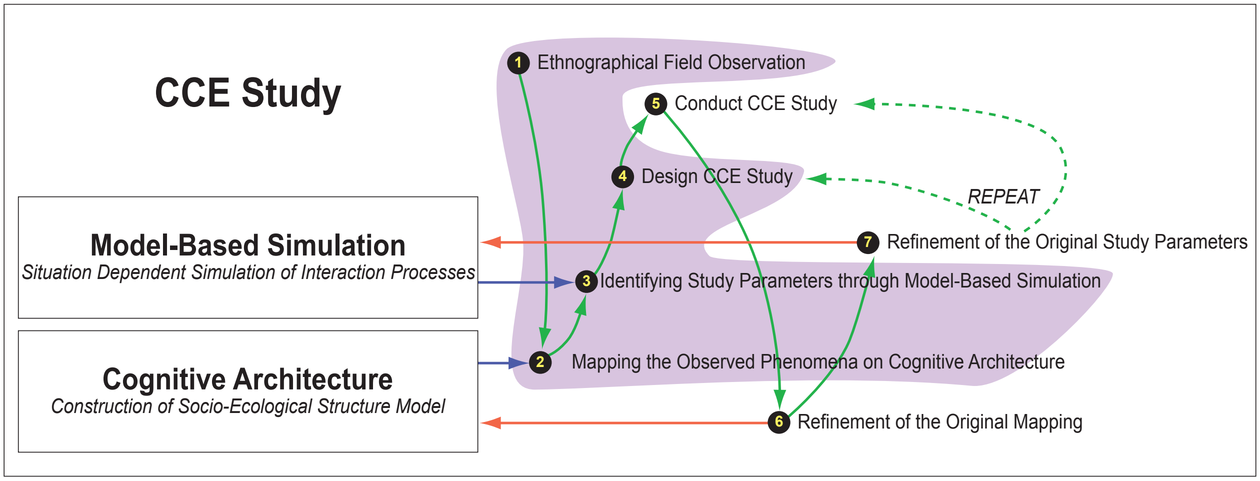

Figure 2. The CCE procedure [15, Figure 5.1].

it is vital to assume the correct happiness goal when simulating a problem-solver's next action selection processes.

III. Achieving SDGs by Applying CCE

The gossips in Banerjee et al.'s study [17], who pursued a certain happiness goal while selecting the appropriate next actions to be performed as real-world problem-solving activities, happened to contribute to achieving one of the SDGs. The upper portion of Figure 1 depicts this as "Mapping of accomplished individual Task Goals to societal SDGs." Banerjee et al. [17] hypothesized that those persons who were nominated by villagers as people who would be good at transmitting information in a network would be highly central individuals; and that sending information via such nominated individuals would lead to significantly wider diffusion of information than sending it via randomly chosen people, or even respected ones. They tested this hypothesis by conducting RCT studies, and succeeded in bridging the gap between achievement of any of the SDGs and accomplishment of individual task goals by selecting the appropriate individuals for making this possible. This section describes a cognitive scientific approach to what Banerjee et al. [17] did by integrating all the portions shown in Figure 1.

A. *Cognitive Chrono-Ethnography (CCE)*

This paper focuses on the particular study methodology of the CCE [23]. CCE is helpful in building an understanding of people's daily action selection processes by combining three concepts. "Cognitive" declares that CCE deals with interactions between consciousness and unconsciousness in the PCM cycles. "Chrono(-logy)" suggests that CCE concerns itself with the time dimension for characterizing human behavior, including not only short-term action sequences, but also relatively long-term behavioral changes, ranging from $\sim$ 100 msec to days, months, and years, i.e., spanning through the COGNITIVE, RATIONAL, and SOCIAL bands. "Ethnography" indicates that CCE takes ethnographical observations as a concrete study method because in daily life, people's Two Minds tend to re-use experientially effective behavioral patterns, which is called "cognitive biases." Ethnographical field observations are essential for understanding each person's biases in his or her daily life. In order to conduct a CCE study, study participants (elite monitors) are selected. Each point in the parameter space defining the study field has values. The study question is "what such-and-such people would do in such-and-such way in such-and-such circumstance (not an average behavior)." Therefore, elite monitors, i.e., such-and-such persons, are selected by consulting the parameter space. In this process, it is necessary that the points in the parameter space, which correspond to the elite monitors, are appropriate for analyzing the structure and dynamics of the study field. Monitor selection is conducted by purposive sampling rather than by random sampling, similar to the RCT methodology.

B. *CCE Procedure Adapted to SDGs Achievement*

This subsection shows the steps for conducting a CCE study adapted for understanding people who are practicing daily real world problem-solving activities, leading to accomplishment of the SDGs, as shown in Figure 1. This understanding can be used for exporting such people's activities to potential followers who can then contribute to the achievement of the SDGs in the future [24]. Figure 2 shows the seven steps to conduct a CCE study [15, Figure 5.1]. Described below are the CCE steps adapted to the problem of SDGs achievement. Necessary additions appear after the general descriptions of the CCE procedure.

(1) *Ethnographical Field Observation:* Use the basic ethnographical investigation method to clarify the outline of the structure of social ecology that underlies the subject to be studied.

> Here, the study's focus would be any social ecology that has achieved or is approaching accomplishment of any of the UN defined targets associated with one of the 17 SDGs. The purpose of the CCE is to understand how this goal accomplishment is possible in the social ecology in question. Therefore, the enabling condition for a CCE study is the existence of such a social ecology, i.e., there is an ecologically valid solution for achieving the target under the SDGs.

(2) *Mapping the Observed Phenomena on Cognitive Architecture:* With reference to the behavioral characteristics of

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people, which have been made clear so far, and the cognitive architectures, consider what kind of characteristic elements of human behavior are involved in the investigation result in (1).

> The emphasis is on identifying a plausible happiness goal that might be held by the people in question. This step is particularly important, because the happiness goal is normally different from the target of the SDGs, each of which resides in different bands.

(3) *Identifying Study Parameters through Model-Based Simulation:* Based on the consideration of (1) and (2), construct an initial simple model with the constituent elements of activated memories, i.e., meme, and the characteristic PCM processing to represent the nature of the ecology of the study space.

> The focus would be to identify classes of behaviors that are distinguishable from each other due to different functioning of their PCM and memory processes. The bottom part of Figure 1 is achieved by using appropriate cognitive architecture, such as MHP/RT [13][14][15] by assigning plausible ranges of values for the model parameters, which would result in a number of distinguishable behavioral patterns. For example, in the case of spreading information concerning vaccination, the cognitive processes might differ depending on the nature of information to be spread. This means that a more sophisticated treatment of spreading information could be carried out than that attempted by Banerjee et al. [17], by taking into account the underlying PCM and memory processes.

(4) *Design a CCE Study:* Based on the simple ecological model, identify a set of typical behavioral characteristics from a variety of people making up the group to be studied. Then formulate screening criteria of elite monitors who represent a certain combination of the behavioral characteristics, and define ecological survey methods for them.
(5) *Conduct CCE Study:* Select elite monitors and conduct an ethnographical field observation. Record the monitors' behavior. The elite monitors are expected to behave as they normally do at the study field. Their behavior is recorded in such a way that the collected data is rich enough to consider the results in terms of the parameter space, and as un-intrusively as circumstances allow.
(6) *Refinement of the Original Mapping:* Check the results of (5) against the results of (2) for appropriateness of the mapping. If inappropriate, go back to (2) and restart the process from there.
(7) *Refinement of the Original Study Parameters:* If the result of (5) is unsatisfactory, go back to (4) and redesign and conduct a revised CCE study, otherwise go back to (3) to redo the model-based simulation with a set of refined parameters.

On completion of a CCE cycle, the existing social ecology that has contributed to the achievement of any of the SDGs is understood as a feasible scenario that could be transferred to another social ecology that is similar to the existing one, but has still not achieved the goal.

IV. Conclusion

This paper discussed the contribution of cognitive science to the achievement of the SDGs, taking as an example, the communication of vaccination information that lead to the achievement of health goals. There is room for consideration as to whether the targets set to achieve all SDGs can be advanced in the same way. However, as stated in the UN report [1], it is impossible to achieve the targets without human involvement. In that regard, cognitive science, dealing with human behavior is destined to make a significant contribution. This paper first linked social-level goals of the SDGs to their associated individual-level happiness goals, and then associated the latter with human behavior. This association shows that inducing actions that lead to individuals working toward their happiness goals can lead indirectly to the achievement of the SDGs. In this way, scenarios for achieving the SDGs have been and can be created.

For instance, concerning the goal of attracting tourists to tourist destinations, CCE has proven to be effective in understanding tourists' activities in a previous study [25]. The tourists had different happiness goals organizing their behavior; these happiness goals were sorted into combinations of Target Happiness goal with one or two goals out of Sensual, Cerebral, and Chemical Happiness goals. The total number of combinations was six. Each of the combined happiness goals were found to be associated with characteristic tourists' behavior, i.e., eating, strolling, bathing, shopping, playing, and relaxing. The social level goal that was indirectly achieved by the tourists' behavior was the revitalization of the economy of tourist destinations. Although this is not one of the social goals under the SDGs, it nonetheless shows the feasibility of the CCE study methodology in the context of the achievement of SDGs.

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