Improving decision making through visual knowledge calibration

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Abstract

Purpose – This article aims to explore the so-called illusion of explanatory depth (IOED) of managers regarding their understanding of digital technologies and examines the effect of knowledge visualization one's current understanding and decision making. Its purpose is to show that managers think they know more than they do and that this affects decision making but can be reduced through knowledge visualization.

Design/methodology/approach – In two experiments with experienced managers, the authors investigate the size and impact of the IOED bias in decision making and examine if sketched self-explanations are as effective as written self-explanations to reduce the bias.

Findings – The findings show that experienced managers suffer from a significant illusion concerning their explanatory understanding of digital technologies and that sketching one's current level of explanatory understanding of these technologies supports the accurate calibration of one's knowledge. The findings indicate that sketching knowledge is a helpful modality for the detection and subsequent recalibration of biased knowledge in domain-dependent decision making.

Originality/value – This article is the first to explore the effect of sketched knowledge externalization on the calibration of explanatory knowledge of managers. It extends the literature on both, the IOED and on knowledge visualization as an instrument of knowledge calibration.

Keywords Technology led strategy, Decision making, Business strategy, Management, Psychology, Individual behavior

Paper type Research paper

1. Introduction

This study looks at a crucial factor of managerial decision making: the *knowledge about one's own knowledge*, its impact on managerial decisions and how managers can make knowledge gaps explicit to improve their decision making. To do so, we follow the call for knowledge visualization to improve managerial decision making in the digital age (Schiuma *et al.*, 2022) and apply a seminal concept from cognitive psychology to the managerial realm, namely the *illusion of explanatory depth* (IOED) (Rozenblit and Keil, 2002). We provide three contributions: The proof of the existence of an IOED in assessing digital technologies, the impact of these limitations on managerial decisions, and an analysis how self-sketched knowledge visualizations can help to calibrate one's own knowledge and reduce one's overestimation of knowledge. The article provides scholars and managers with insights of how an IOED about emerging digital technologies may flaw the outcome of managerial decision making and how and why self-sketched visualizations reduce this illusion.

Managerial decision making in the digital age calls for understanding digitization and its underlying technologies (Wrede *et al.*, 2020). This is a prerequisite for successful digital business transformation and competent strategic decision making (Rachinger *et al.*, 2018). The lack of understanding of novel, emerging technologies feeds uncertainties with regard to their economic potential and value creation (Kapoor and Klueter, 2021). As such an understanding and a potential adoption requires significant knowledge and experience (Shih, 2020) the knowledge of managers about strategy-relevant emerging digital technologies (Brockmann and Anthony, 2002; Smith *et al.*, 2005) is hence critical for strategic decisions.

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Thus, an accurate self-assessment of this knowledge (Furnham and Boo, 2011) to understand the strengths and weaknesses of emerging digital technologies has become crucial for the managerial decision-making process (Fitzgerald *et al.*, 2013; Kane *et al.*, 2015).

A flawed understanding of emerging digital technologies, a miscalibration of one's own knowledge about them, may be hazardous. It may seduce managers to overly rely on their own (flawed) expertise instead of seeking advice from experts or other internal or external collaborators (Alba and Hutchinson, 2000; Singh *et al.*, 2015; Walters *et al.*, 2017). It may lead to poor strategic decision making when it comes to the assessment of emerging digital technologies and their potential value creation (Kapoor and Klueter, 2021).

We have chosen to explore a specific perspective of miscalibrated knowledge: the "illusion of explanatory depth" (Rozenblit and Keil, 2002). The IOED is the illusion of people to "understand complex phenomena with far greater precision, coherence, and depth than they really do" (Rozenblit and Keil, 2002, p. 521). The phenomenon of an IOED emerges because of "people's limited knowledge and their misleading intuitive epistemology" (Rozenblit and Keil, 2002, p. 522). It leads to an inaccurate self-assessment of one's own knowledge (Fisher and Keil, 2016). Reducing the IOED leads to better managerial decisions (Bailey, 2021). In their seminal experiments, Rozenblit and Keil (2002) have already shown that a *written* self-explanation calibrates the assessment of explanatory knowledge for devices like zippers or helicopters and thus reduces this illusion. The calibration effect of alternative modes of self-explanations (such as self-sketched drawings) has not been researched until now.

Following a recent emphasis on knowledge visualization in managerial practices (Schiuma *et al.*, 2022) and the role of knowledge visualization in decision making in the digital age (Zhao *et al.*, 2022), we have chosen to explore the potential for self-drawn visualizations (sketches) for the calibration of an illusion in explanatory knowledge for emerging digital technologies. Visualizing knowledge addresses the cognitive challenges of managerial thinking (Vaz *et al.*, 2022), helps to understand ideas (Gavrilova *et al.*, 2017), and provides ad hoc feedback loops (Eppler, 2011; Weck *et al.*, 2022).

With our experiments, we first analyze whether the phenomenon of an IOED can also be observed among managers and their explanatory knowledge of emerging digital technologies such as blockchain, big data analysis, augmented reality etc. Second, we examine if such miscalibrated knowledge has an impact on the subsequent decision behavior of managers. And third, we assess, if knowledge visualization supports the calibration of this illusion.

We thus ask the following research question: can (self-drawn) visualizations help to (re) calibrate one's explanatory knowledge of emerging technologies to uncover and even correct this illusion? Can sketches improve managerial decision making by creating awareness and reducing the impact of the IOED?

2. Theoretical background and hypotheses

2.1 The illusion of explanatory depth in managerial decisions

The understanding of how emerging digital technologies work involves knowledge about complex causal patterns (e.g. explaining how blockchains or augmented reality applications technically work) and – as a result – is therefore prone to the IOED. Rozenblit and Keil (2002) define four features or typical challenges regarding explanatory knowledge: the confusion of the internal representation and the environmental support, the confusion between the different levels of analysis, the complexity of hierarchies of explanation leading to an indeterminate end state of the explanation, and the rarity of reproduction of an explanation. The understanding of how emerging digital technologies work is "explanatory, theory-like knowledge that may converge to convince people they have vivid, blueprint-like senses of how things work, even when their actual knowledge is skeletal and incomplete"

(Rozenblit and Keil, 2002, p. 522). Emerging digital technologies are characterized by layers of contents, services, networks, devices and the combination of hardware and software (Henfriedsson *et al.*, 2014). Therefore, they exhibit the "problem of unbounded causal complexity" (Keil, 2007, p. 1036) with complex hierarchical structures of the mechanisms behind the phenomenon and – consequentially – indeterminate end states of explanation (Rozenblit and Keil, 2002). Thus, the knowledge about how emerging digital technologies work, fulfills all four features of explanatory knowledge. The environmental support (e.g. interfaces, displays) and the (incomplete) internal representation of the mechanisms behind may lead to confusion. Emerging technologies show different and iterative levels of analysis. This leads "to an illusion of understanding when a person gains insight into a high level function and, with that rush of insight, falsely assumes an understanding of further levels down in the hierarchy of causal mechanisms" (Rozenblit and Keil, 2002, p. 523). As managers are often generalists (Ferreira and Sah, 2012), they rarely "give explanations and therefore have little information on past successes and failures" (Rozenblit and Keil, 2002, p. 523).

The breadth of experiments conducted on the IOED has shown that it not only affects technical or natural domains, but also concepts from other domains, such as political policies and positions, voting issues, historical events (Alter *et al.*, 2010; Fernbach *et al.*, 2013; Gaviria and Corredor, 2021; Roeder, 2016; Sloman and Vives, 2022; Vitriol and Marsh, 2018; Voelkel *et al.*, 2018), mental disorders and treatments (Zeveney and Marsh, 2016), science based behavioral recommendations for health improvement and climate protection (Bromme *et al.*, 2016), as well as explanations for artifical intelligence (Chromik *et al.*, 2021). As these examples show, the effect of uncovering the IOED increases "the awareness about one's own cognition (understanding, attitude, argument strength)" (Bromme *et al.*, 2016, p. 106). This effect is not only observed in the context of understanding manmade devices or technologies, but for other concepts as well, where the superficial understanding at an abstract level produces an overestimation of one's understanding of the causal patterns behind the surface – concepts like the explanatory knowledge of emerging digital technologies. This leads us to our first hypothesis:

H1. Managers suffer of an IOED when it comes to their explanatory knowledge of emerging digital technologies.

As stated above, an IOED represents a miscalibration of knowledge, overconfidence in this specific type of explanatory knowledge (Rozenblit and Keil, 2002). The impact of overconfidence on managerial decisions has been shown in various contexts. Overconfidence in one's own abilities leads to business entry mistakes (Camerer and Lovallo, 1999) and influences risk taking after performance feedback (Schumacher *et al.*, 2020). It leads "to conclude that a situation is less risky" (Busenitz and Barney, 1997, p. 25). The overestimation of investment returns results in overpay for target companies (Lee *et al.*, 2017; Malmendier and Tate, 2005), and excessive trading (Barber and Odean, 2001). As the IOED represents an overestimation of one's abilities to explain a certain technology, we assume that managers who suffer of an IOED will be overly confident about a positive decision where a digital technology is involved and are willing to invest more in such a venture. On the other hand, we assume that managers who discover their IOED and recalibrate their explanatory knowledge will be more risk-averse and reduce their willingness to invest in a certain venture. This follows the finding that "the price a person is willing to pay for a financial option is a function of risk" (Frijns *et al.*, 2013, p. 2458). The amount that a person is willing to invest measures risky behavior (Weber and Hsee, 1998), as a higher investment indicates greater (intended) strategic risk taking (Chng and Wang, 2016). As overestimation of one's knowledge leads to the perception that a specific "situation is less risky" (Busenitz and Barney, 1997, p. 25), we hypothesize:

H2. The recalibration of an IOED leads to a significant reduction in the individual willingness to invest in a digital technology venture.

We now turn from the problem-oriented hypotheses to the solution-oriented ones.

2.2 Calibration of knowledge and the promise of visualizations

A miscalibration is a deviation from the accuracy of a decision (Tang *et al.*, 2014). Thus, calibration helps to close the gap between the expressed confidence (subjective confidence) and the accuracy of a decision (objective quality) (Koriat, 2012; Sniezek and Henry, 1989; Tang *et al.*, 2014). Calibration raises the degree of certainty (Alba and Hutchinson, 2000), reduces the tendency to take inappropriate actions (Maule and Hodgkinson, 2003) based on inaccurate managerial perceptions (Pillai, 2010), and improves information search (Pillai and Hofacker, 2020). This view is also expressed in the following quote:

> Perfect calibration exists when one's belief in the veracity of the knowledge (confidence) matches the correctness of that knowledge (accuracy) (Pillai, 2010, p. 301).

Such a calibration of knowledge can be achieved by training (Gutierrez de Blume, 2017; Moore *et al.*, 2017) or by feedback on the accuracy of one's judgment or decision (Tang *et al.*, 2014). Another way of calibration is deliberate reflection, i.e. "to go back to the case" (Costa Filho *et al.*, 2019, p. 231). This enables a disfluency effect by lowering the confidence (Sniezek and Henry, 1989), retrieving the unknowns (Walters *et al.*, 2017) and thus supports the calibration of knowledge. "In contrast, the ease that is facilitated by fluency leads to greater use of heuristic reasoning, and sometimes more errors in judgment" (Hernandez and Preston, 2013, p. 178), thus "processing fluency may be one important factor that determines when people will overcome their intuitive responses to engage more systematic reasoning" (Alter *et al.*, 2007, p. 575).

Rozenblit and Keil (2002) have already shown that a *written* self-explanation of a phenomenon recalibrates the explanatory knowledge of people and revealed that this was in fact the effect of accurate recalibration and not "a result of feeling 'challenged'" (Rozenblit and Keil, 2002, p. 533). Mental representations like a self-explanation enable managers "to see things they were not aware of, and this insight helps them to define new questions, hypotheses, and models of their data" (Van Wijk, 2005, p. 3). The benefit of self-explanations for calibration is also supported by research on learning: "by generating inferences to fill in missing information, integrating new information with prior knowledge, and monitoring and repairing faulty knowledge, learners who self-explain develop more accurate internal representations of a concept" (Kim *et al.*, 2017, p. 1376). The existing experiments on the IOED have used only the written mode of self-explanations following the original protocol. Thus, there is a research gap in exploring alternative modes of self-explanations to reduce the IOED.

Over the last years, knowledge visualization has become an emerging area of research and has received more and more attention in managerial decision making (Moretto *et al.*, 2022; Schiuma *et al.*, 2022). Graphic representations support the strategic planning process (Eppler and Platts, 2009), help to map strategic consensus (Tarakci *et al.*, 2014), and support transparency and inclusion in open strategy contexts (Paroutis and Knight, 2019). The use of visualizations enhances strategy tools in their interactive role to facilitate creativity, meaning, discourse and knowledge creation and sharing in strategizing (Jarzabkowski and Kaplan, 2015; Knight *et al.*, 2018; Paroutis *et al.*, 2015; Pfister and Eppler, 2012). Knowledge visualization supports the subsequent communication and hence implementation of strategies (Kernbach *et al.*, 2015). Visualizing knowledge helps "decision makers to understand the complexity of their business" (Yan *et al.*, 2022, p. 1096). Visualizations support the signaling of skills and competencies and have become more and more a critical aspect of managerial decision making (Troise, 2022). They structure and externalize original

internal or implicit knowledge (Brockmann and Anthony, 2002; Mengis and Eppler, 2006). Visual representations are in fact "more effective than verbal explanations in representing sequential and hierarchical relations" (Guri-Rozenblit, 1988, p. 219) and show the major components of complex causal patterns and the interaction of these components (Mayer and Gallini, 1990). As knowledge visualizations provide feedback loops (Eppler, 2011; Weck *et al.*, 2022), help to switch perspectives (Yan *et al.*, 2022) and enhance the understanding of one's own uncertainty (Hullman *et al.*, 2018) we hypothesize that a visual mode of self-explanation may calibrate the IOED as well as a written self-explanation or even better.

Compared to other visual representations like diagrams, maps or images, sketching has several advantages (Eppler and Burkhard, 2007). Sketches are "hand-drawn, simple drawings on a poster, flipchart, piece of paper or via a digital pen on a tablet PC or an electronic interactive whiteboard" (Pfister and Eppler, 2012, p. 373). Sketches are fast and no artistic skills are necessary which provides a low entry barrier for its use in managerial decision making (Walny *et al.*, 2015). Sketches are imprecise, unfinished, make abstract principles and knowledge easier handleable, and bring unconscious nuances to consciousness (Platts, 2001). Sketches help to coordinate external and internal perspectives and allow people to compute more deeply, broadly and more precisely, to "communicate with themselves" (Kirsh, 2010, p. 444) through the incremental and "step-by-step" process of sketching what they know. Their vagueness and amorphousness allows displaying and accepting uncertainties (Swedberg, 2016). The provisionality and openness of sketching (Bresciani and Eppler, 2018; Hundhausen, 2005) creates a "disfluency", an "interruption of the smooth flow of thought" (Ellis, 2018, p. 123). Disfluency makes "people more critical and analytical of that information" (Hernandez and Preston, 2013, p. 179).

Following these different attributes and strengths of knowledge visualizations and especially self-drawn sketches, we hypothesize that the task of a sketched self-explanation helps to reduce the IOED and calibrate explanatory knowledge even better than a written self-explanation. This leads to two separate hypotheses:

H3. A visual (sketched) self-explanation leads to a stronger correction of the IOED than a textual self-explanation.

H4. A visual (sketched) self-explanation leads to a more accurate calibration of explanatory knowledge than a textual self-explanation.

3. Methods

To test the four hypotheses described in the previous sections, we have developed two experiments and a coding scheme to analyze the written and sketched (visual) self-explanations of the participants (details for the coding scheme can be seen in the online supplementary file). The first experiment explored the managers' IOED for emerging digital technologies and how a sketched vs. a written self-explanation supports the calibration of explanatory knowledge to answer H1, H3 and H4. The second experiment focused on the consequences of the recalibration of explanatory knowledge for a managerial (investment) decision (H2).

3.1 Experiment 1

3.1.1 Sample. For the first experiment, we have enlisted a total of 78 participants, of which 59 were experienced managers (age 30+) who had enrolled in management seminars and workshops and 19 experienced professionals enrolled in different MBA (Master of Business Administration) programs (age 25+). Regarding participant demographics, the mean age of the sample was 38.3 years, with 15.0 years of work experience and 8.1 years of management experience. 56 were males, while 22 were females. They came from 11 different countries

(a majority from European countries) and covered more than 15 different industries. The experiment was conducted on-site during a management training session.

3.1.2 Procedure. The first experiment partially replicates the original IOED-experiment by Rozenblit and Keil (2002). As it is our main goal to explore the IOED for the specific area of digital technologies and especially the effect of two different forms of self-explanations (see hypotheses H1, H3 and H4), we focus on the first four experimental steps of the original experiment as they are sufficient to reveal an IOED ("participants felt their knowledge self-ratings . . . were accurately low even after they read the expert explanations" (Rozenblit and Keil, 2002, p. 530)). As the original experiment already has shown the calibration effect of a written self-explanation, we have changed the original step 3 by exploring a second condition for a self-explanation, a sketched one, which allowed us to compare the calibration effects of both self-explanation modes (test versus image).

Step 1 – Basic Calibration: To indicate their level of understanding, the participants learned to use a 7-point scale to rate their understanding (deep, partial, shallow) of complex causal patterns on two training examples (the understanding of the concepts of return on investment (ROI) and the Global Positioning System (GPS) – the second example was taken from the original experiment).

Step 2 – Measure T1: The participants then rated their *level of understanding* (T1) of seven digital technologies. We have chosen these seven key digital technologies as they were mentioned by Forbes as key digital trends (https://www.forbes.com/sites/danielnewman/2017/09/26/top-10-trends-for-digital-transformation-in-2018/#42fc2926293a). These seven technologies are generally considered to have a major impact on strategic decisions for a company. In fact, they are consistently cited in various publicly accessible management publications and websites as the key technologies relevant for business today. They are: artificial intelligence, blockchain, Internet of things (IoT), 5G mobile communication, virtual reality, augmented reality and big data analysis. Thus, it could be expected that today's managers are aware and have a certain understanding of these technologies and how they affect their business model. All seven technologies fulfill the features of explanatory knowledge.

Step 3 – Measure T2: For three of these technologies (following the design of the original experiment by Rosenblit and Keil), all participants were asked to deliver a self-developed explanation (how does this technology work?). The three technologies (blockchain, IoT, augmented reality) were chosen because of their different level of complexity and conceptuality (blockchain: decentralized network with defined functionality; IoT: open network structure; augmented reality: hardware/software connection, defined functionality). The participants were randomly assigned to one of the two mode conditions: 50% of the participants had to deliver a *written* explanation, while the other 50% of the participants had to create a *sketched* explanation. After the explanation, the participants rerated their understanding of all seven items (T2) so that we could capture any possible recalibration in their self-assessment after this intervention.

Step 4 – Measure T3: For each of the three technologies where a self-explanation was requested, the participants were then asked a detailed "diagnostic question" (e.g. how is a crypto currency built and what makes it work?) which they had to answer in writing (for both conditions). Then, all participants re-rated their level of understanding for all items one final time (T3).

At the end of the experiment, all participants had to complete a short questionnaire about their background (age, gender, work experience, managerial experience, industry, country of origin).

Thus, every participant rated his or her understanding of the seven digital technologies three times: T1 (the original self-rating), T2 (the self-rating after they have created a visual or written explanation of the technology) and T3 (the self-rating after a diagnostic question concerning the technology and their own written answer).

3.2 Experiment 2

3.2.1 Sample. The participants of the second experiment consisted of 117 managers which participated in international strategy and communication workshops and trainings (unrelated to the participants of the first experiment). They were from 23 different countries (with an average age of 37 years, 13.4 years of working experience and 5.7 years of management experience). The experiment was conducted during the management trainings and workshops.

3.2.2 Procedure. The second experiment was based on the original IOED protocol as well combined with an investment situation to examine the influence of the IOED on an investment proposal. We replicated the first three original steps for the group of randomly assigned participants (until T2) to explore the recalibration of an IOED (concerning the explanatory knowledge of the involved technology) and to compare their investment proposal results with the control group without a calibration (self-explanation) intervention.

We started the experiment by letting the participants watch a video sequence from the Canadian television show "Dragon's Den" where a start-up called Phazon (focusing on an easy-to-know digital technology topic: wireless earbuds) was presented and one of the investors closed with a concrete offer for the whole company (4 million dollars – the external investment anchor in our experiment). After watching the video, all experiment participants had to complete an online survey where they were asked how much they would invest in the company? (Answers within a range from 0–5 million $, label: invest 1) and then they were asked to rate their understanding of how wireless earbuds work (T1, scale of 1 (no idea at all) to 7 (excellent understanding)). Half of the participants were then randomly assigned and asked to explain in a written statement what they know about how wireless earbuds work and to rate their knowledge again after this written explanation (T2). They were then asked again for their willingness to invest (label: invest 2). At the end, all participants were asked about how much they would invest in the company again (same range as before – label: invest 3).

4. Results

4.1 The managers' illusion of explanatory depth

The results of the first experiment are aligned with the predictions of the established theory of IOED in other domains and confirmed hypothesis 1. The participants showed a *significant drop in the self-ratings from measure T1 to T3* (T1: $M = 3.38$, standard deviation (SD) = 0.077; T2: $M = 2.79$, SD = 0.077, T3: $M = 2.54$, SD = 0.077; repeated measures analysis of variance (ANOVA): F (2/1611) = 31.37, $p < 0.0001$) thus confirming that *managers originally overestimated their explanatory knowledge of emerging digital technologies*. This is also in line with the argument by Gaviria *et al.* (2016) that the high social desirability of specific knowledge like digital technologies contributes to an IOED (i.e. the fact that managers are supposed to understand digital technologies).

For a more detailed analysis of the results, we applied an ex-post coding scheme (see online supplementary file) to code the quality of the self-evaluations. A contingency analysis relating gender and the self-evaluation groups showed a significant distinction between *male and female self-evaluation and re-calibration* ($\chi^2(8, N = 234) = 26.05$, $p = 0.001$): *Men tend to keep their overestimation of understanding digital technologies and correct their initial view less*

than women, confirming the gender gap in overconfidence (Barber and Odean, 2001; Bengtsson *et al.*, 2005; Buser *et al.*, 2020) (see Table 1).

4.2 How the calibration of explanatory knowledge influences decisions

The analysis of the IOED calibration (the adjustment between the first rating and the second rating after the self-explanation) and the adjustment of the investment proposal between the first and the second investment statement in experiment 2 showed a significant correlation. The size of the IOED calibration predicts the adjustment of the investment proposal in the second investment statement (ANOVA: F (1/54) = 5.67, $p < 0.0208$). Thus, the bigger the recalibration of knowledge (self-evaluation adjustment) is, the greater the reduction of the intended investment towards a smaller strategic risk. This confirms hypothesis 2: *Managers who re-calibrated their initial rating of their own explanatory knowledge of a digital technology indeed reduced their willingness to invest in a digital technology venture.*

Thus, recognizing an overestimation in explanatory knowledge has an impact on the individual decision.

Additionally, we have checked whether the change in the willingness to invest was due to an order effect based on the experimental procedure or indeed provoked by the recalibration of explanatory knowledge. In other words: Do managers with a recognized IOED reduce their intended investment because they recalibrated their explanatory knowledge or just because of a "simple" order effect by being repeatedly asked the same question?

If the correction of the investment intention for the IOED group would have been due to an order effect and not because of the recognition of an IOED, then there should have been no significant difference in the adjustment of the investment intention between those who corrected their initial rating and those who did not. To check for such an order effect, we have split the IOED group in those who recalibrated their knowledge and those who did not (due to correct self-evaluation or a stable overestimation) and compared their final investment propositions (invest 3) and the size of the adjustment between "invest 1" and "invest 3" with those from the control group. The repeated measures ANOVA showed a *significant difference* between the investment proposal adjustments of the three groups between the "invest 1" and "invest 3" decisions (control group M = 165'574, SD = 109'789; IOED not corrected M = 153'125, SD = 151'583; IOED corrected M = 931'250, SD = 175'033; F(2/114) = 7.69, $p = 0.0007$) – see Figure 1. The comparison within the IOED manipulation group (corrected vs. no correction of IOED) showed a significant difference (invest3 corrected M = 1'160'416, SD = 307'063; invest3 not corrected M = 1'684'375, SD = 265'925; F(1/54) = 7.46, $p = 0.0085$), supporting the case for a knowledge calibration effect based on the self-explanation that is clearly different from an order effect.

4.3 The promise of visualizations

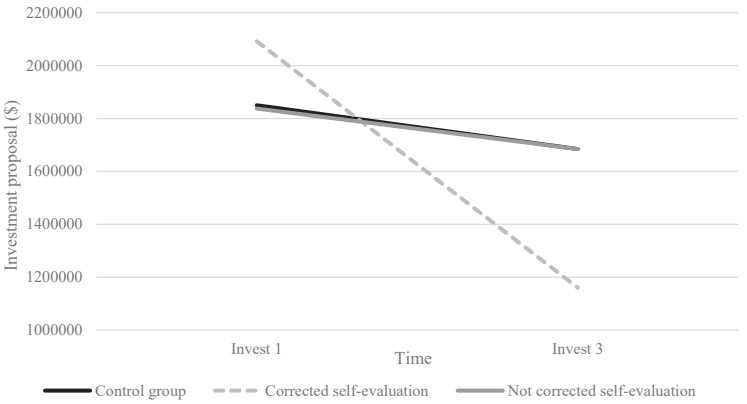
The analysis of the results of experiment 1 concerning the two conditions (sketched/visual and written self-explanation) showed that a sketched self-explanation (M = 0.701, SD = 0.067) leads to a significantly *higher* adjustment of the self-rating from T1 to T2 than a written self-explanation (M = 0.494, SD = 0.069), $t = 2.15$, $p = 0.0324$, df = 536. *A visual (sketched) self-explanation thus leads to a significant stronger correction of an IOED,* which confirms hypothesis 3.

The contingency analysis for experiment 1 relating the two conditions (text and visual) and the ex-post coded groups of self-explanations showed a significant difference ($\chi^2(8, N = 234) = 25.05$, $p = 0.0015$) of the calibration effect (see Table 2). To analyze whether the visual self-explanation even led to a more accurate calibration, we used two binary categories of calibration based on the coding scheme: correct calibration (variable 1, those results which were correct from the beginning and those which were calibrated correctly) and incorrect

Table 1. Contingency analysis experiment 2 for male/female overestimation

	No correction	Over-estimation (OE) corrected	Under-estimation (UE) corrected	Over-corrected OE	Over-corrected UE	OE	UE	Corrected but still OE	Corrected but still UE	Total
Female	31	17	0	1	0	5	6	5	1	66
Male	38	55	7	2	2	38	6	19	1	168
Total	69	72	7	3	2	43	12	24	2	234

Note(s): Comparison of the calibration effect on gender
Source(s): Table by authors



Note(s): Checking for an order effect: Control group: invest 1 = 1'850'000, invest 3 = 1'684'426; corrected self-evaluation: invest 1 = 2'091'666, invest 3 = 1'160416; Not corrected self-evaluation: invest 1 = 1'837'500, invest 3 = 1'684'375
Source(s): Figure by authors

Figure 1.
Overview order effect vs. IOED effect

calibration (variable 0, all other results, still over- or underestimating one's knowledge). The result of the one-tailed *t*-test comparing the effect of the visual or textual condition on the correct or incorrect calibration *showed a significant more accurate calibration for those with a visual self-explanation* (text $M = 0.57$, SD = 0.045; visual $M = 0.683$, SD = 0.044; $t = -1.66$, $p = 0.0493$, df = 232), confirming hypothesis 4.

5. Discussion, implications, and limitations

5.1 Discussion

As the understanding of digital technologies to make sound strategic decisions becomes more crucial in the digital age, the result of our study provides helpful insights for managers concerning their technological knowledge and self-assessment. The results of our experiments show that managers of all kinds tend to systematically overestimate their explanatory knowledge of the complex causal patterns of contemporary digital technologies, creating a "positive illusion" about their own know-how. Additionally, our study is the first one to show that the mechanisms behind the IOED can indeed be applied to the managerial realm and to managerial decision making. We have not only shown the size of this illusion, but also that it has an impact on managerial decisions, as does the recalibration of knowledge.

The application of self-drawn sketches to extract one's own knowledge about a certain topic explored the calibration potential of knowledge visualization. Our results clearly show that a visual representation of explanatory knowledge allows managers to create awareness and reduce the impact of the IOED in their decision making. As a result, we have a positive answer to our main research question: self-drawn sketches to externalize knowledge about a specific topic improve managerial decision making. They help to uncover a particularly subtle sort of knowledge overconfidence and help to accurately calibrate one's individual knowledge about digital technologies.

5.2 Implications for research

Our study answers the call for using contemporary cognitive concepts to study managerial decision making and to explore the practical potential of knowledge visualization to improve

Table 2. Contingency analysis experiment 1: textual vs visual calibration

	No correction (NoC)	Overestimation (OE) corrected	Underestimation (UE) corrected	Overcorrected OE	Overcorrected UE	OE	UE	Corrected but still OE	Corrected but still UE	Total
Textual	31	30	5	1	1	28	1	17	0	114
Visual	38	42	2	2	1	15	11	7	2	120
Total	69	72	7	3	2	43	12	24	2	234

Note(s): Comparison of the calibration effect between the ex post coded groups of experiment 1 and the two conditions (visual and textual self-explanation)
Source(s): Table by authors

decision practices (Schiuma *et al.*, 2022, p. 887) and the related cognitive processes (Yan *et al.*, 2022, p. 1096).

The result of the first experiment contributes to knowledge visualization research by showing the effect of the provisionality of self-sketched visualizations on individual knowledge calibration. The stronger generation of disfluency in a visual representation than in a textual one, and the effect that "one discovers in the process of drawing some aspects were simply absent from the image" (Reisberg, 1987, p. 289), support the knowledge calibration more effectively and more accurately than a written self-explanation. Thus, our study shows that calibrating knowledge with visualizations addresses the cognitive challenges of managerial decision making (Vaz *et al.*, 2022), and provides useful ad hoc feedback loops (Eppler, 2011; Weck *et al.*, 2022) that make managerial decisions more accurate. This result opens the gate for more research on how knowledge visualization may help to reduce the impact of other cognitive biases in managerial decision making.

5.3 Implications for practice

Our research shows that the *externalization of knowledge*, i.e. the visual representation of ones understanding of complex causal patterns in the form of sketches, can help managers to calibrate their knowledge more accurately. Miscalibrated knowledge leads to flawed decision making in management (as it reduces a manager's propensity to consult others, for example). This deviation from an accurate decision (Tang *et al.*, 2014) leads to the intention to take riskier decisions (in domains that one does not understand well) as shown in our second experiment. Therefore, by *sketching* what they know about a specific topic, managers can effectively reduce their IOED and actively debias their decisions. Having shown that an IOED exists in managerial topics (as in many other domains) and impacts decision making, we would also encourage managers to calibrate their knowledge diligently and repeatedly when making decisions about new ventures. This provides a face-saving way for managers to admit that they have not fully understood important technologies or concepts.

5.4 Limitations

The experiments presented in this study face several limitations. First, they focused on the mode variations of text versus drawings. The form of an oral self-explanation was not examined. Thus, further research could focus on other techniques and tools of disillusioning than the individual visualization of one's knowledge, as could be an in-depth analysis under which conditions visual methods are more or less effective in adjusting an inaccurate anchor or which kind of visualizations support debiasing knowledge illusions best, as "visualization designs affect decisions" (Xiong *et al.*, 2020, p. 853).

Second, actual *in situ* managerial behavior was not analyzed in our research. Experiment 2 focused on the change in *intention*. We acknowledge that this did not measure the actual risk behavior (Reypens and Levine, 2018), as there are often gaps in willingness to pay and actual behavior (Nelson *et al.*, 2012). But to measure a change in intention due to the awareness of one's own limited explanatory knowledge (a different mindset before and after the re-calibration of this knowledge) serves as the closest proxy to come by in an experiment without spending money and buying real companies.

Third, as the original procedure of the IOED experiments showed the difficulty of a "traditional" control group (you cannot check for existing knowledge before the experiment without influencing the results of the self-evaluation), we have used the results of the self-explanations compared with an "averaged reference" to control for actual knowledge in both experiments. The choice of these references and their coding is not perfect and we thus tried to minimize the influence of these subjective choices by categorizing the results broadly (low, medium, high knowledge, for example).

Fourth, the impact of an IOED has been measured on a simple investment example based on an individual's choice and not on complex, team-based strategic decisions. We have thus excluded social factors such as cultural patterns, groupthink effects, social desirability bias etc. These issues should be integrated in future research on the phenomenon of an IOED in management.

Nevertheless, the results show that *visualizing what you think you know* is one effective way to improve managerial decision making that we recommend to further explore in research and to apply more often in practice. In this way, managers can become, with a little help from visualizations, aware of the limitations of their own knowledge and hence reduce this bias in their decision making.

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Appendix

The supplementary material for this article can be found online.

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