

Publication Network Visualization as an Approach for Interdisciplinary Innovation Management

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Abstract - *Interdisciplinary research is currently the central scientific approach, assumed to be the answer to large-scale research problems (e.g., health and aging, economics and production in high wage countries). Although it is quite popular, there is still a lack of knowledge about how to measure, steer, support, and manage interdisciplinary success.*

This paper presents an approach to analyze, steer, and manage the structure and success of interdisciplinary cooperation by implementing a publication network visualization tool into an interdisciplinary research cluster.

The presented study is an exploratory interview study addressing the significance of mixed node publication visualization usage within interdisciplinary teams. Members of a sample research group (N = 5) were asked to evaluate the publication visualization approach in order to find out more about the usefulness of such a tool for the interdisciplinary workflow. First results show that benefits of such a tool are seen in the ease of finding potential partners for cooperation. Barriers were seen, on one hand, in the limitation of parameters that can be visualized, and on the other hand, in effects that could follow an implementation (e.g., pressure to publish, competition between team members, etc.).

Index Terms: *Interdisciplinary innovation management, interdisciplinary research, network analysis, self-measurement, publication analysis.*

INTRODUCTION

Interdisciplinary research is a central scientific approach, especially today [1]. Although there has been no systematic and unified definition of the term since its advent in the 1950s [2] [3], and a vast amount of synonyms and related expressions (transdisciplinary,

multidisciplinary, etc.) exist, a central criterion emerged: The different definitions and expressions always describe a connection of at least two disciplines in one research context.

The idea that interdisciplinary research teams perform better than those confined to a single discipline is quite popular since important innovations have been made in the context of interdisciplinary research clusters [2]. This success disseminated the interdisciplinary research approach. Especially high wage countries like Germany support research in interdisciplinary cooperation to address large-scale research problems (e.g., health and aging, economics and production) [4]. One example for specific support of interdisciplinary research is the “Cluster of Excellence - Integrative Production Technology for High-Wage Countries” (funded by the German Research Foundation (DFG) in context of the *Excellence Initiative* of the Federal Republic of Germany) at RWTH Aachen University [5]. The Cluster of Excellence “...aims at developing a viable, production-scientific strategy and theory of production including necessary technology approaches.” It is an interdisciplinary large-scale research cluster consisting of more than 20 institutes of material and production technology of RWTH Aachen University [4].

Although interdisciplinarity promises to be a successful approach to face the great challenges in current research, its success cannot be taken for granted. Interdisciplinarity is much more than just putting representatives of different disciplines into one team. Extra effort is necessary to achieve true synergies and to form a joint approach. The combination of different scientific disciplines, cultures, and methods into one research cluster leads to many challenges on various levels: Different cognitive research models, different methods, and different scientific languages used in

different scientific cultures must be conquered to generate a productive level of cooperation [6].

The Cluster of Excellence “Integrative Production Technology for High-Wage Countries” faces these exact challenges. Structures that support, steer, and examine scientific cooperation were established in the form of so-called *Cross Sectional Processes* [CSP] [7]. “CSP are supporting networking processes and strategic cluster developments by means of learning and knowledge management.” [7]. One core area of CSP is the approach of *scientific cooperation engineering*, i.e., the systematic and controlled implementation of joint research that combines methodological and theoretical expertise from different specialties into a novel research output. The approach of scientific cooperation engineering was developed during and after the first funding period of the Cluster of Excellence (2006 - 2012) [8][9][10]. Based on the insight that huge interdisciplinary research clusters need extra support in form of cluster-specific measures that can be used to manage the interdisciplinary structures successfully, CSPs were institutionalized in the second funding period. [7]. One keystone of scientific cooperation engineering is the so-called interdisciplinary innovation management. This approach is presented in the section below.

Interdisciplinary Innovation Management

Interdisciplinary innovation management addresses the challenges of interdisciplinary work. One pivotal aim is the generation of rules for successful interdisciplinary cooperation as well as support through (interactive) interventions: *measuring and visualizing the cooperation activities allows researchers to evaluate themselves (in comparison with others) and understand group activity and social research structures*. The central approach for interdisciplinary innovation management therefore is a visualization tool that is conceptualized, filled with appropriate parameters, developed and tested within the current funding period of the cluster of excellence. Furthermore, this approach is the focal subject of this paper.

In the following section, the genesis and related work for the approach of the publication visualization tool is presented. Then, the main focus of this study and questions addressed are worked out. This is followed by the presentation of the methodology of the study, executed in the context of the visualization tool, and the results. The final section of this paper contains a discussion of central results, a conclusion as well as limitations of this study and an outlook on future research.

PUBLICATION NETWORK VISUALIZATION A TOOL FOR INTERDISCIPLINARY INNOVATION MANAGEMENT

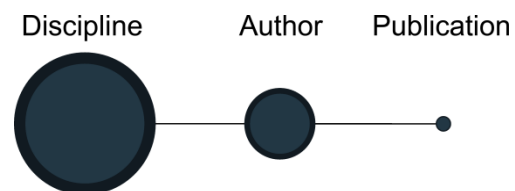
This section presents an approach for a publication visualization tool designed for the interdisciplinary

innovation management as an instrument for steering, measuring, and analyzing interdisciplinary team success. It also offers a self-measurement service for researchers to place themselves within interdisciplinary research teams.

The idea of visualizing publication habits to analyze interdisciplinary success

The idea for a visualization tool that illustrates interdisciplinary success was born in the context of a quite successful interdisciplinary research project at RWTH Aachen University. The reason for its development was trying to make interdisciplinary success visible to official appraisers. According to the groups’ self-evaluation the extent of interdisciplinarity across the team had been well developed, though no metrics were available to visualize or even measure interdisciplinary success. Because of the group’s success within the field of publications, publications were chosen as an initial point of reference. Although long lists of publications are quite impressive, they are not useful for presenting in-depth information on the circumstances of their interdisciplinary creation process, or the social process of reciprocal understanding across disciplines within the team.

In order to face these problems, a visualization of all publications was generated. In a first step, we used simple co-authorship graphs. These were not useful to illustrate the character of interdisciplinary work but allowed a first insight in what disciplines produced joint publications. This is why the concept of a mixed node graph was developed [11]. This concept allows visualizing authors, their publications as well as their discipline (Figure 1) in one single graph.

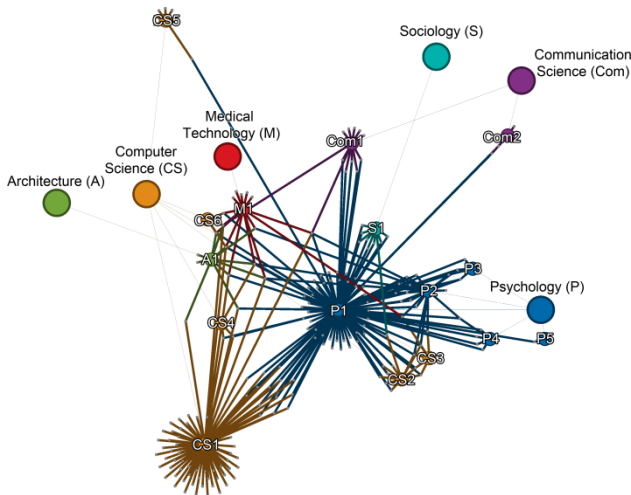


Source: Calero Valdez et al. 2012

FIGURE 1: MIXED NODE PUBLICATION GRAPH WITH DIFFERENT TYPES OF NODES

The visualization of the graph was realized by using the open source software Gephi [11]. The final version of the visualization was able to illustrate all publications connected with the authors and disciplines involved, in a chronological way (Figure 1 and 2 and <http://vimeo.com/48446978>). As figure 1 illustrates the publications were illustrated by little bubbles, authors by medium sized points and the authors’ disciplines with large bubbles. The final version also allowed a coloration of authors according to their discipline, to make the visualization easier to interpret (Figure 2).

The effect of seeing this visualization was quite inspiring within the team and not only impressive to external evaluators. Even though every person involved already knew everything about his/her own publications and co-authors, the visualization illustrated the underlying social structures of the current team perfectly. Beyond that, looking at the graphs and discussing the outcomes induced new ideas of joint cooperation work. Apparently, picturing publication networks is able to facilitate social behavior and increase team identity. Based on the observation that single researcher got interesting insights in their own work, we suggest to use this too additionally as an instrument for self-control by the group.



Source: Calero Valdez et al. 2012

FIGURE 2: SAMPLE MIXED NODE PUBLICATION GRAPH

These illustrations inspired us to intensify working on the concept and to develop metrics that could be transferred to other research projects dealing with the challenges of interdisciplinarity.

Summing this section up, the approach of publication analysis with mixed node publication network graphs can be regarded as a potential approach for analyzing interdisciplinary effort, success, and cooperation quality. The next section deals with the integration of this concept into the process of interdisciplinary innovation.

After the quite successful first presentation of the mixed node publication analysis, the concept was further developed to leverage its benefit for bigger interdisciplinary teams. In particular graph statistical analyses (e.g., centrality parameters, graph entropy, community detection) were used to create objective means for measuring group success. Hence, the approach was tailored to the interdisciplinary research cluster “Integrative Production Technology for High-Wage Countries.” In this context, the publication visualization approach was designed in order to fulfil three main tasks:

- Measuring interdisciplinary success

- Steering the interdisciplinary research cluster
- Support researchers in the interdisciplinary workflow (self-measurement)

Within a period of five years (2012 - 2017), the approach should be developed into a serviceable, validated tool that can be used to support interdisciplinary teams to work in a more effective and efficient way.

MAIN FOCUS OF THIS STUDY AND QUESTIONS ADDRESSED

This research presents a first exploratory study to investigate the usefulness and suitability of mixed node publication network visualizations as a tool to steer, analyze, and measure success in interdisciplinary research teams. It also examines its potential as a self-measurement tool for researchers. Therefore, we consulted members of a sample interdisciplinary research team to evaluate the approach according to a post hoc presentation of their own publication history via a mixed node publication visualization.

The central research questions are:

- Are mixed node publication network graphs suitable to visualize the structure of interdisciplinary teams?
- Are mixed node publication network graphs suitable to steer interdisciplinary success?
- What do observers learn from the visualization in regards to self-measurement?
- Does the mixed node publication visualization approach have the potential to support interdisciplinary cooperations?

Based on these research questions, the following hypotheses have been developed to be answered within this study:

- H1: Mixed node publication network graphs are appropriate to visualize interdisciplinary structures.
- H2: Mixed node publication graphs are suitable to steer research clusters or groups.
- H3: Mixed node publication network graphs have a positive impact on the self-management of researchers.
- H4: There is a positive impact of mixed node graphs on interdisciplinary work.

In relation to the presented research questions and hypotheses, the next section presents the methods used in this research.

METHODOLOGY

In order to get a first, exploratory insight into the potential of publication visualization as an instrument for analysis, steering, and self-management in/for interdisciplinary teams, the method of semi-structured interviews was chosen.

The interviews were divided into four main parts. *Part one* contained questions about the general validity of the tool to represent interdisciplinary team performance. *Part two* addressed the suitability of the visualization approach to be used as a steering instrument for interdisciplinary research groups. *Part three* asked for an evaluation of the impact (positive vs. negative) of mixed node publication visualization on interdisciplinary work. *Part four* focused on the evaluation of the approach as a tool for self-measurement for researchers, to place themselves within their team as well as to analyze their performance or search for cooperation partners.

The introduction to the interview was a short presentation of a prototype of the visualization tool. The presented visualization was an exact depiction of the publications of the sample team. The presented visualization showed all names of the team members as well as all disciplines and the publication titles (due to facts of data privacy see an anonymized example in Figure 3), generated according to the reduced graph described in [11].

Due to the fact that there is no full-fledged application available, we could only present the visualization in form of static images of every year of interdisciplinary work in this team constellation (from 2009 to 2012) and offer a zoomable OpenSeadragon export. All participants were instructed that they were only seeing a prototype of the future tool.

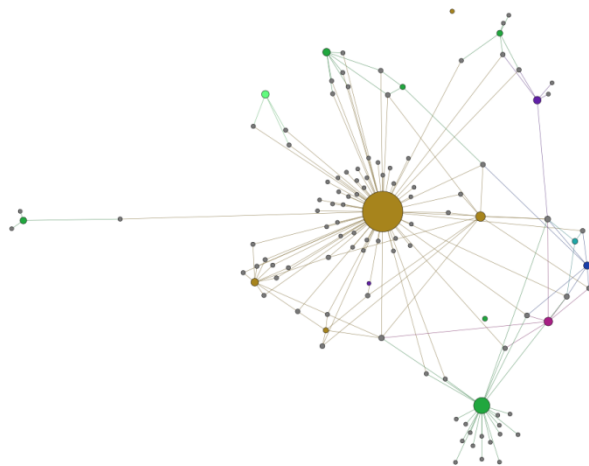


FIGURE 3: ANONYMOUS MIXED NODE PUBLICATION NETWORK GRAPH OF THE SAMPLE RESEARCH TEAM IN THEIR SECOND YEAR (2010) OF COOPERATION

After the presentation of the prototype, participants were asked to evaluate the potential of the visualization tool with respect to its potential for visualizing, analyzing, and steering interdisciplinary success as well as rate its applicability as a tool for self-measurement.

Sample

In order to get deeper insights into the topic, we chose a qualitative approach with a limited sample size rather

than collecting a larger sample of questionnaire data, taking the early stadium of the study into account. The study is based on a sample of 5 participants who were familiar with this kind of visualization. All participants were members of one interdisciplinary research team. At the time of the interview, each participant had been a member of the team for two or more years and had written at least two publications. The whole research group (visualized in the graph) consisted of 15 team members working in different third-party funded projects but for the same associate chair.

The age of the participants ranged from 29 to 37 years. The scientific core areas of the sample are: psychology (n=2), computer science (n=1), architecture (n=1), and communication science (n=1).

RESULTS

In order to investigate the potential of a mixed node publication visualization tool for interdisciplinary innovation management, we conducted five semi-structured interviews. The interviews were evaluated according to the principles of quantitative content analysis [13][14], to extract a first explorative view of the attitude of interdisciplinary research team members towards publication visualization as a tool for self-measurement, steering, and analysis.

According to the research hypotheses, the subsequent section is structured as follows:

First, the evaluation of the tool's capability to visualize interdisciplinary structures in research groups is presented. *Second*, the participants' assessment of the approach according to its steering abilities is worked out. *Third*, the experts' appraisal of the approach as a self-measurement tool is presented. To finish this section the *fourth section* presents an overall evaluation of the approach, addressing the tools overall impact on interdisciplinary work, presented in form of naming and counting general pro and con items.

Publication visualization as means to demonstrate interdisciplinarity (RQ1)

Regarding the question whether mixed node publication network visualization is a suitable approach to present interdisciplinary team success, the participants' evaluation reveals a divided image: n=3 confirmed that the tool represents interdisciplinary team performance in an adequate way. The other participants (n=2) were not totally convinced of the tool's suitability. The restrictions were basically seen in the specific intention for the demonstration behind the scenes:

P1: "...it depends on what the visualization shows. You can only see the total amount of publications everyone has, without further information about the workload of the specific person..."

Additionally, we asked for a description of the personal performance of each participant from his/her own perspective and from the perspective of the other team members. Results revealed that n=3 confirmed an adequate representation. The others named a *distortion of reality* based on quick unselected interpretation (n=2) and the *missing ability for parameter modification* (n=1) as limitations.

Summarizing, the trend is towards a positive evaluation of the approach in general, with limitations addressing the accuracy and distortion of reality based on missing depiction of parameters like workload, publication outlet, etc.

Publication visualization for steering interdisciplinary research groups (RQ2)

The suitability of the approach for steering interdisciplinary teams was confirmed by n=4. Benefits were seen in the *ease of uncovering gaps of cooperation* and the *level integration*. Critical considerations addressed misgivings about publications being made to score in the team *competition* and not for the content value of published work. Additionally, one participant remarked that networking is not the only criterion for the value of a research group what underlines that other success factors should be implemented.

All in all, the potential of the publication visualization approach as a steering tool is evaluated rather positively. Restrictions were seen in the significance of mere publication counting and the limited focus on one aspect of team performance.

Publication visualization as a self-management tool (RQ3)

Asking the participants about the suitability of the tool for self-measurement of single researchers in the context of their group revealed rather negative image. On one hand, there is an interest to see *connections and structures* (n=2) that are regarded as an incentive for publishing with others. On the other hand, it was remarked that this particular visualization *is limited to one research group*, and thereby does not offer a more comprehensive image of one's actual performance (n=1) (e.g., publications with authors from other institutions). Another objection was the visualization of well known facts which is redundant:

P5: “...this approach would not help me, I mean I actually already know the visualized facts...”

A second question in this context asked about the willingness to use the tool frequently for self-measurement. Similar to the evaluation of general fitting of the tool for self-measurement there is a differentiated attitude: Only one participant would use it personally as it is. Another two participants would use it for

benchmarking or the target search for research partners. The main objections are the *unspecific statement of success* (n=1) when using this tool, the *missing definition of evaluation criteria* (n=1), and a threatening pressure to use it.

Asking about the suitability of the publication visualization approach to help single researchers place themselves in big interdisciplinary research teams is quite positive. N=4 confirmed a positive impact on *finding researchers for cooperation* (n=2) as well as learning more about the subtleties of scientific disciplines.

In summary, there is no consistent attitude towards the impact of the visualization approach as a tool for self-measurement. There are positive as well as negative characteristics of the approach that influence the attitude of the participants. In the following section, an overall image of the impact of publication visualization on interdisciplinary teamwork is presented.

Impact of publication visualization on interdisciplinary work (RQ4)

The upcoming section summarizes the total of pros and cons mentioned during the evaluation of the publication visualization approach as a tool for interdisciplinary innovation management. Based on three subjects, a) *representation of scientific structures*, b) *steering instrument for interdisciplinary teams*, and c) *publication visualisation tool for self-measurement*, a set of pro and con items could be identified. The results presented below create the foundation for the final discussion.

The Pros

In total, we found 41 positive remarks attributed to the presented approach of mixed node publication network visualizations. These remarks can be grouped into 9 categories (Figure 4).

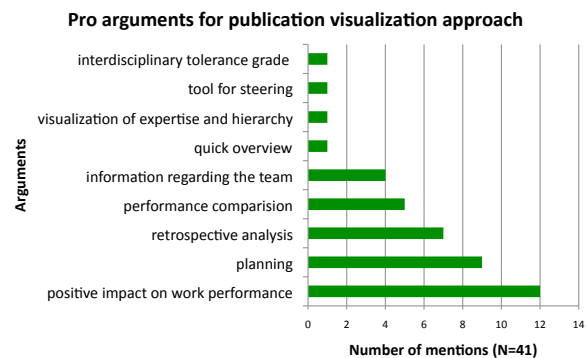


FIGURE 4: CATEGORIES OF PRO ARGUMENTS FOR PUBLICATION VISUALIZATION

The three most frequent pro arguments stated by the participants in the context of publication visualization are *positive impact on work performance* (n=12), *planning*

(n=9) and *retrospective analysis* (n=7). Other aspects such as *comparison* (n=5) and *information regarding the team* (n=4) are also quite frequent.

Summarizing this section, the pro publication visualization arguments are basically addressing the positive impact on the workflow as well as the option of easy measurement and analysis of team performance.

In the next section, these arguments are contrasted to the con arguments addressing the visualization approach.

The Cons

In addition to the pro items we also found 29 con items that can be grouped into 10 categories (Figure 5).

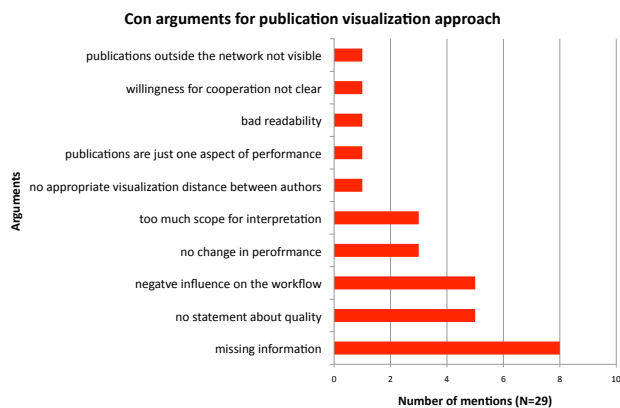


FIGURE 5: CATEGORIES OF CON ARGUMENTS FOR PUBLICATION VISUALIZATION

The most prominent contra argument was the evaluation of *missing information* (n=8) in the visualization, which lead to the second con argument: *no statement about quality* (n=5). The third important objection addresses a *negative impact on the workflow* (n=5). In comparison to the other two con arguments, this one is focused on the reactions such a tool could provoke in research teams. Other con aspects mentioned in this study addressed the missing impact on the *change in performance* (n=5) or the usability aspects (*no appropriate visualization distance between authors* (n=1) or *bad readability* (n=1)).

Summing up the pro and con section, there is a *dominance of pro items* (N=41) that underline a positive impact of the approach on the *work performance*, *steering abilities* of interdisciplinary teams, and *performance measurement*. The con arguments take a warning role and urge not to forget aspects of usability and interpretation guides.

CONCLUSION

Due to the fact that interdisciplinary research is always a challenge for the researchers involved, this study presented a qualitative approach for mixed node

publication network analysis as a tool for the interdisciplinary innovation management. Possible areas of application that were evaluated in this research were: *steering interdisciplinary teams*, *analysis and evaluation of interdisciplinary teams*, and *self-measurement* for researchers.

The outcome of the study revealed varying degrees of concerns among the participating researchers. These polarizing findings and the small number of participants do not allow falsification of hypotheses but indicate directions of further research and support the expectation that personalized publication analyzes is both complex in regard to computation and human acceptance. Nonetheless findings can be related to our hypotheses and are therefore summarized and discussed in the following section.

For H1, "*Mixed node publication network graphs are able to visualize interdisciplinary structures.*" we can say mentioned benefits addressed a positive impact on areas of interdisciplinary research teams that are known to be critical: e.g., transparency, support for planning interdisciplinary work, benchmarking for interdisciplinary success as well as support for interdisciplinary cooperation.

Regarding H2, "*Mixed node publication graphs are suitable to steer huge research cluster or groups,*" the experts attested an exceptionally positive influence on large interdisciplinary research clusters. Arguments for that evaluation were seen in the ease of recognizing and illustrating structures within large teams.

The potential of the tool as an instrument for self-measurement was rated fair to middling. Although a potential was seen in the support for a general positioning of researchers, participants were critical in the context of the representation of their own data. Therefore, limitations of the display format were named in this context (e.g., missing visualization of workload, publication outlet, etc.). This finding can neither confirm nor reject H3, "*Mixed node publication network graphs have a positive impact on the self-management of researchers.*"

Regarding H4, "*There is a positive impact of mixed node graphs on interdisciplinary work,*" we can state that researchers see a positive impact of publication visualization but also are not yet totally convinced by its benefits.

All in all we can say that on the one hand, the visualization approach is regarded to have the potential to be a helpful instrument in overcoming the challenges of interdisciplinary teamwork. On the other hand, the named limitations raised our awareness to focus on modalities for a strategic introduction of the tool as well as schooling options. Additionally, finding the perfect field of application seems to be prudent. Focusing on the character of teams and target introduction strategies could

avoid dismissal and resistance against the tool in interdisciplinary teams.

LIMITATIONS AND FUTURE RESEARCH

This research offers two valuable insights to follow up on: First, the approach of mixed node publication network visualization is very promising if we succeed in developing integrated metrics that reflects publication success and underlying social habits among team members. Second, this study underlined the impression that there is still a lot of work to do and that the approach must be further developed until it will be applicable. We recognized that it is essential to integrate practitioners' feedback much more. Out of this research we derived limitations that lead to suggestions for future research activities:

Due to the fact that the sample of this study was rather small we have to consult more participants in the future. Another limiting aspect was the status of the prototype used in this study. The static pictures and unanimated visualization portrayed the approach in a rather unrepresentative way. An advanced prototype might have avoided critique in the context of the visualization level.

Other restrictions can be seen in the lack of variation of hierarchical levels future users can have. Especially in the context of evaluating the approach's potential as a steering instrument, it is essential to also integrate team leaders, professors, etc.

The found limitations lead us to central findings that must be taken into account for future research:

First, the missing reproduction of different hierarchical levels will be taken into account in future studies on the evaluation of the publication visualization approach. *Second*, future studies will focus on bigger research teams, thereby taking into account team size as a potential acceptance parameter. *Third*, more parameters (e.g., workload, outlet of publication, methods used in the paper, etc.) will be integrated into the prototype to find out if such variety enhances the usefulness of the tool.

It remains to summarize that the approach of mixed node publications visualization as an instrument for interdisciplinary innovations managements can still be regarded to be a promising tool to face the challenges of interdisciplinary work. Therefore, it is important to maintain research in the context of this approach to improve the approach and enhance it into a serviceable tool.

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