

A Social Network Analysis of Faculty Mentees Funded by the Research Initiation in Engineering Formation (RIEF) Program

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Abstract—Contribution: Our work focuses on building research capacity in engineering education research (EER) by studying a group of engineering faculty who are participating in a mentorship-based training grant to learn EER.

Background: The US National Science Foundation’s Research Initiation in Engineering Formation (RIEF) is a funded mentorship-based training grant for engineering faculty without prior EER experience who seek to conduct EER. This funding requires that the faculty mentees work with an experienced social science researcher during a two-year project. During this time, mentees must undergo a paradigm shift from engineering research to social science, which includes building research skills and becoming enculturated into the EER community.

Research Questions: What are the characteristics of RIEF mentees’ professional networks for engineering education research? How do RIEF mentees’ networks change over time, as operationalized by professional interactions, communication about the RIEF project, and collaborations?

Methodology: We use social network analysis to investigate the development of EER professional networks of RIEF mentees and their interactions with other research community members during the first year of their research initiation training.

Findings: Overall, mentees’ professional networks for EER increased (i.e., reported more connections) after one year. However, when mentors had limited prior connections to the EER community, their mentees’ social networks for EER are isolated compared to mentees whose mentors have a higher number of connections to community members. Our findings have implications for mentored training programs, suggesting that well-connected mentors are best placed to enculturate mentees into a research community.

Index Terms— Capacity building, enculturation, Research Initiation in Engineering Formation (RIEF), research mentoring, social network analysis, social capital.

I. INTRODUCTION

THERE HAVE been numerous efforts over the last two decades to build capacity for engineering education research (EER). Global and US-based initiatives such as the Engineering Education Research Colloquies and the Advancing Global Capacity for Engineering Education Research workshop series helped crystallize engineering education as a field in its own right according to [1]–[4]. US capacity building efforts for the field focused first on introducing engineering faculty to aspects of conducting EER through trainings such as the Rigorous Research in Engineering Education workshops (2004–2006) which included skill development and mentoring components [5]. Around the same time (2004), the first US

engineering education PhD programs were formed at Purdue University and Virginia Polytechnic Institute and State University [6]. In the years since, the EER community has continued to build capacity via training of both students and faculty.

Engineering faculty learning how to conduct engineering education research face two main challenges. Firstly, transitioning from technical engineering research to EER requires a paradigm shift [5] in order to learn to pose significant questions, utilize appropriate theoretical frameworks, and measure and operationalize constructs. Secondly, the shift requires faculty to become enculturated into new research community [5].

EER communities of practice and one-on-one mentorship are designed to address this second challenge; the US National Science Foundation (NSF) has offered significant funding for the latter. Since 2011, NSF has invested nearly \$23M in the Research Initiation in Engineering Formation (RIEF) program and its predecessor, the Research Initiation Grants in Engineering Education program [7]. RIEF grants are awarded to engineering faculty (mentees) who are experts in technical engineering disciplines but novice EER researchers. Mentees learn EER techniques with the guidance of one or more experienced social science or education researchers (mentors). Projects are awarded for two years with a maximum budget of \$200,000. The RIEF solicitation requires prospective investigators to submit a mentoring plan in addition to the description of the proposed EER project. NSF weighs the mentoring plan heavily in the review process.

II. RESEARCH QUESTIONS

Our work focuses on the enculturation of engineering faculty into the EER community by studying (1) the development of EER-related professional networks of RIEF mentees and (2) interactions of mentees and mentors with other EER community members. We use social network analysis to investigate the following research questions:

RQ1: What are the characteristics of RIEF mentees’ professional networks for EER?

RQ2: How do RIEF mentees’ networks change over time, as operationalized by professional interactions, communication about the RIEF project, and collaborations?

III. SOCIAL CAPITAL THEORY

We ground this project in Lin's network theory of social capital [8]. Broadly defined, social capital describes the information and resources inherent in relationships. Lin's theorization of social capital focuses on networks of individuals and is therefore appropriate for understanding the professional networks of RIEF awardees. Social capital is significant for enculturation into a new research community because it serves multiple purposes: it (1) enhances the flow of information, (2) may influence individuals with decision making power, (3) provides social credentials, and (4) provides identity reinforcement [8].

Social capital has been widely used as a framework to study mentoring relationships in STEM higher education. Mentors provide instrumental support to their trainees in the form of research training and access to their professional networks [9], and expressive (or psychosocial) support, such as encouragement [10], [11]. Mentors help mentees build social capital via professional socialization, exposure, visibility, and sponsorship [10], [12].

Prior qualitative studies of RIEF mentoring relationships have demonstrated specific mechanisms associated with the four elements of social capital. For example, a mentor who introduces their mentee to other members of the EER community reinforces the mentee's identity as an engineering education researcher and increases their sense of belonging and recognition because their mentor's influence and credentials carry weight with other community members [13]. Identity reinforcement and sense of belonging is especially important for enculturation of engineering faculty entering the EER community because they are entering a the field via a non-traditional trajectory and are "starting from scratch" in new academic community without the benefit of doctoral coursework and formal training experiences [11], [14]. Building robust social networks for EER is especially important for faculty mentees who are at institutions with minimal EER resources in part because it combats feelings of isolation and builds belonging in the larger EER community [14].

IV. RESEARCH DESIGN

A. Social Network Analysis

Social network analysis (SNA) is a technique that can reveal information about an individual within a group and whole group characteristics [15], [16]. Using SNA, researchers can identify relationships between people. For example, researchers can identify individuals (termed "nodes") who have high influence by their number of connections (termed "degrees") to other individuals. Investigators can also track connections that share resources and information that comprise social capital [15], [16]. Important people in a network may connect two groups, serving as the bridge through which resources and information are shared.

SNA uses ego network data—that is, it focuses on an individual's reporting of their connections to other nodes—to characterize and visualize their social network [16]. Researchers can collect data about an individual's connections by providing respondents with a list of people (a closed network) or asking respondents to generate a list people

themselves (an open network) [16]. Researchers may include additional survey questions to gauge the type of relationship or strength of each connection, also called a "tie" [16].

B. Terminology

Throughout this paper we use terminology consistent with SNA methodology, parenthetically indicating the terms' meaning in layman's terms for those unfamiliar with SNA. Here we provide a list of key terms for quick reference.

- Nodes—an individual in a network.
- Tie—a connection between two individuals in a network.
- Degrees—the number of connections (ties) one has.
- Bridge—individuals (nodes) that link other individuals into a larger network that otherwise would be fragmented in smaller separate groups if the "bridge" were severed.
- Isolate groups—groups or individuals that are connected to each other but are not connected to the larger network.

C. Instrument Development

We used a positional approach to SNA by creating a theoretically informed, bounded list of possible network members [17]. In this approach, "Researchers identify informants by using social positions or organizational affiliation as threshold for inclusion" [18]. The technique requires researchers to first define group membership or position then make lists of individuals who occupy those positions [17].

We developed inclusion criteria for relevant positions and groups using our team's prior theoretical experience studying social capital and RIEF mentoring relationships, and our extensive professional experience. The author team members have collectively held several critical positions that have informed this work, such as: the former NSF program director who oversaw the RIEF program, journal editor-in-chief and associate editor, leadership roles within the American Society of Engineering Education, current and past RIEF mentors, a past RIEF mentee, and facilitators for the RIEF virtual community of practice. These combined professional experiences gave us a theoretical and practical vantage point to understand how EER newcomers, and especially RIEF mentees, interact with established EER community members who have built up significant capital and resources to support them.

SNA researchers are required to make inclusion and exclusion decisions for the types of groups or positions based on theory and with a heavy dose of practicality, because the more groups/positions included, the longer the survey will be. This creates a tradeoff between including more individuals on the closed list and the likelihood of receiving complete responses without participants experiencing significant survey fatigue. For larger networks having a list provided reduces the burden on the participant for having to recall people and make decisions [19]. We considered multiple groups/positions for inclusion in the survey, carefully weighing inclusion criteria to balance survey length with theoretical richness. We ultimately decided on the following groups: four education-focused journal editorial boards, leaders in a primary professional

society division, EER department or program leaders at US universities, a group nationally recognized as EER “pioneers,” and current and former NSF program officers for the Engineering Directorate’s Engineering Education & Centers Division, which provides funding for much EER in the US.

- *Journal of Engineering Education*, *Advances in Engineering Education*, *Studies in Engineering Education*, and *Journal of Women & Minorities in Science and Engineering* editorial board members
- American Society for Engineering Education (ASEE) Educational Research & Methods Division (ERM) leadership (2019-2022)
- EER Department chairs and program directors at US universities
- Engineering education pioneers identified via NSF Project No. 1263512 [20]
- NSF program officers for Engineering Education & Centers Division (Broadening Participation and Engineering Education) since 2013

To determine the list of individuals, we collated publicly available lists associated with each group or position (as of August 2021 when we first administered the survey); the resulting closed network survey included a total of 126 unique names. The survey asked respondents to select the individuals from the list with whom they 1) had professional interactions and 2) spoke frequently about their RIEF project and 3) had collaborated, were collaborating, or planned to collaborate.

We surveyed RIEF mentees and mentors around the time their RIEF projects started and asked them to think about the period when they were conceiving of their RIEF project (e.g., writing the proposal) and starting their projects. We surveyed RIEF mentees again around the end of the first year of their projects. We did not ask mentors to complete the second survey as our purpose was to track mentees’ (not mentors’) networks over time.

D. Sampling and Participants

Ten RIEF mentors and nine of their RIEF mentees completed the survey(s). One mentee did not complete the survey; we were unsuccessful in our multiple attempts to obtain data from them.

E. Data analysis

We analyzed data in RStudio using the “igraph” [21], “ggplot2” [22], and “ggraph” [23] packages. We created visualizations which illustrate the connections among mentors and mentees and the EER community. We calculated multiple positional and connectivity features of the plot, including degree of each node and betweenness centrality, a measure of how many times a node acts as a bridge, or link between others in the network [24].

V. FINDINGS AND DISCUSSION

A. RQ1: What are the characteristics of RIEF mentees’ professional networks for engineering education research?

To answer the first research question, we asked mentors and mentees “with whom have you had professional interactions?” at the beginning of their RIEF project. We reported interactions of each mentor and mentee with members of the EER community listed in the survey (Fig. 1). We represented members of the EER community (listed in the survey but not

participants of the study) as circles in these plots. We represented RIEF mentors as squares and mentees as triangles. We represented mentor–mentee pairs (mentors and mentees working together on the same RIEF project) using the same color. The black lines connecting the individuals indicate that the participant selected them as a connection in the survey.

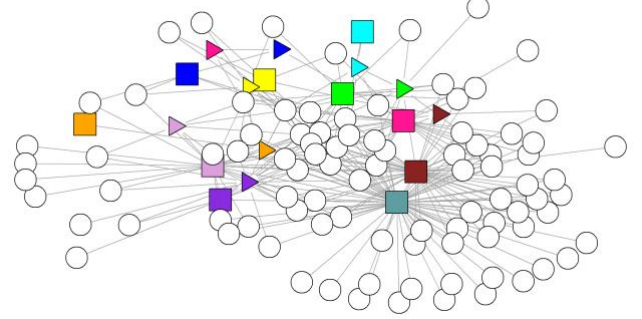


Fig. 1. Professional interactions among RIEF mentors and mentees in the EER community at the beginning of RIEF project. Mentors are represented by squares; mentees are represented by triangles; members of the EER community, not surveyed, are represented by circles. Mentor–mentee pairs are the same color. Black lines indicate a reported interaction.

Fig. 1 and Table 1 both point to the finding that mentees reported lower numbers of interactions with EER community members than did mentors. Examination of the lines connecting mentees (triangles) and mentors (squares) to other individuals (mentees, mentors, and community members selected from the closed list) in Fig. 1 visually depict the degrees reported by each respondent. Degrees are the number of connections (ties) an individual (a node) has to other individuals. We quantified the number of degrees and reported them in Table 1. The interactions mentees reported with members of the EER community were primarily with members of editorial boards (N=100), pioneers (N=36), department chairs/program leaders (N=30), and ASEE ERM leadership (N=21).

TABLE 1
MENTOR AND MENTEE INTERACTIONS WITH EER COMMUNITY MEMBERS
AT THE START OF THE RIEF PROJECT (TIME 0).

Color	Mentor	Mentees
	Degrees	Degrees
Green	13	10
Orange	1	9
Cyan	2	5
Pink	24	3
Brown	51	5
Yellow	9	14
Light Purple	26	6
Violet	7	18
Blue gray	72	--
Blue	5	0

The number of mentor ties with the EER community varied. One mentor (depicted by the orange square) reported one tie with the EER community, and one (depicted by the cyan

square) reported only two ties. These mentors reported being affiliated with a STEM education discipline other than engineering. The mentors who reported one or two ties met the NSF requirement for the RIEF grant in that they possessed the skills needed to help the mentee learn social science research paradigms but had limited EER-specific networks. Some mentors reported connections with each other, which could have a beneficial effect in helping their mentee develop EER community ties.

B. RQ2: How do RIEF mentees' networks change over time?

To answer this research question, we measured professional interactions with members of the EER community, communications about their RIEF project with members of the EER community, and collaborations with members of the EER community.

B1. Table II indicates the number of interactions (degrees) reported by mentees with the EER community. Interactions between RIEF mentees and other members of the EER community increased after one year for seven of the nine mentees. Among the two exceptions, one, depicted as a pink triangle, was paired with a mentor with a high number of connections (24), and the other, depicted as a blue triangle, was paired with a mentor who had a low number of connections (five). Future research might offer reasons for this result. The mentees whose mentors did not have preexisting connections with the EER community (depicted by the orange and cyan triangles) had existing connections to community members (nine ties and five ties, respectively), and we posit that these existing ties contributed to these mentees increasing their number of ties after one year. Our counts include three mentees who reported ties with each other.

TABLE II
MENTOR AND MENTEE INTERACTIONS WITH EER COMMUNITY MEMBERS
OVER THE ONE YEAR PERIOD.

Participant Identity		Time 0	Time 1 Year	Change
		Degrees	Degrees	
Green	●	10	18	+8
Orange	●	9	25	+16
Cyan	●	5	11	+6
Pink	●	3	3	+0
Brown	●	5	24	+19
Yellow	●	14	27	+13
Light purple	●	6	10	+4
Violet	●	18	19	+1
Blue gray	●	--	--	--
Blue	●	0	0	+0

Fig. 2 is a visual depiction of mentee reported interactions with EER community members (answering the prompt, “with whom have you interacted professionally?”). Black lines connect mentees (triangles) and members of the EER community (circles).

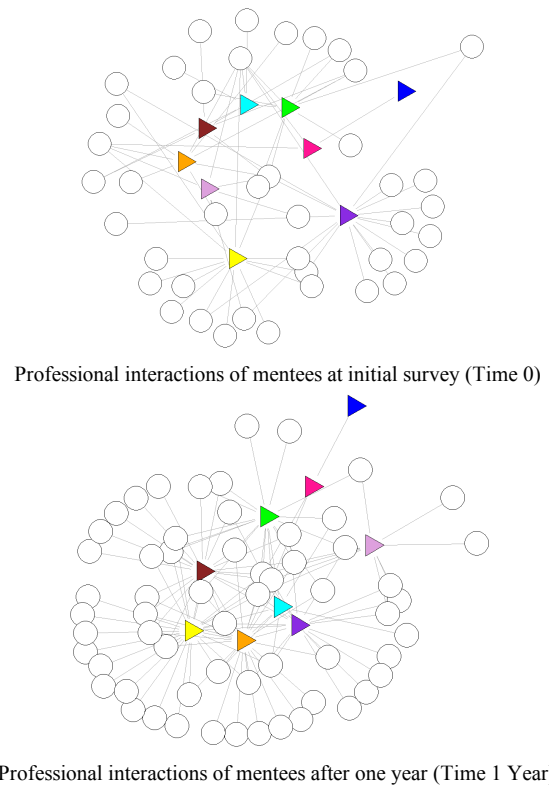


Fig. 2. Mentees' reported interactions with members of the EER community at two timepoints. Mentees are represented by triangles; members of the EER community (not surveyed) are represented by circles. Black lines indicate a reported interaction.

B2. Next, we explored how mentees communicated with EER community members about their RIEF projects. Responses to the question asked at the beginning of the project, “Of the people selected [from the professional interaction list], with whom have you talked frequently about your project?” are indicated in the visualization (Fig. 3) by the lines connecting mentees (triangles), mentors (squares), and members of the EER community (circles).

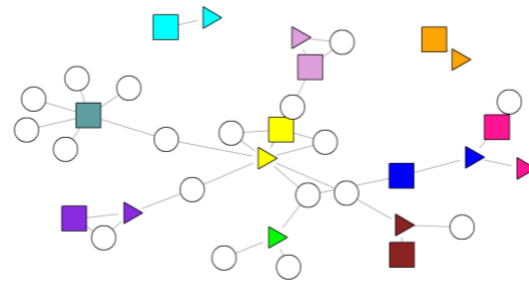


Fig. 3. Reported communications about the RIEF project at the beginning of RIEF project. Mentees are represented by triangles; members of the EER community, not surveyed, are represented by circles. Black lines indicate a reported communication about their RIEF project.

Two mentee–mentor pairs had no communication with EER community members listed on the survey (depicted as orange and cyan pairs); these are the same two pairs for whom the mentees reported existing ties but the mentors reported only one to two interactions with EER community members. One

mentee–mentor pair (depicted by the pink square and triangle, respectively) reported a connection to the mentee depicted by the blue triangle, who reported no professional interactions with EER community members. This may indicate that these participants had different ideas of what constituted a professional interaction.

Mentees’ communication about their own research with others in the community increased over the first year of the project (Fig. 4, Table III). After the first year, mentees are connected to each other directly or by bridge nodes (individuals that link others into a larger network that otherwise would be fragmented in smaller separate groups if the “bridge” were severed) after one year. Fig. 4 depicts the visualization of mentee communication at Time 0 and one year later.

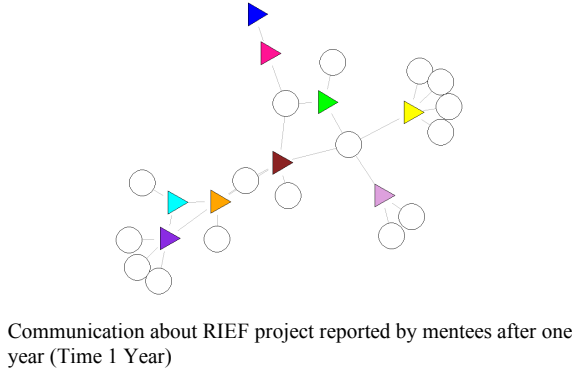
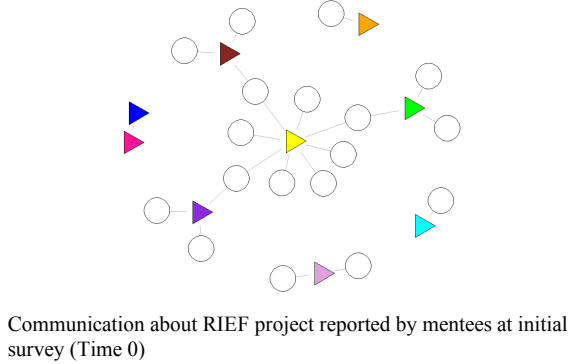


TABLE III
DEGREES REPORTED BY MENTEES REGARDING THEIR PROFESSIONAL INTERACTIONS WITH THE EER COMMUNITY OVER THE ONE YEAR PERIOD.

Participant Identity		Time 0	Time 1 Year	Change
		Degrees	Degrees	
Green	●	10	18	+8
Orange	●	9	25	+16
Cyan	●	5	11	+6
Pink	●	3	3	+0
Brown	●	5	24	+19
Yellow	●	14	27	+13
Light purple	●	6	10	+4
Violet	●	18	19	+1
Blue gray	●	--	--	--
Blue	●	0	0	+0

Next, we explored how mentees collaborated with members of the EER community. Responses to the question, “Which of the people you selected [as having had professional interactions with] are past, current, future collaborators?” are indicated by the lines connecting mentees (triangles) and members of the EER community (circles) depicted in Fig. 5.

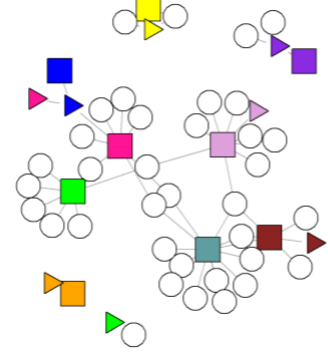


Fig. 5. Lines indicate collaborations between respondent and members of the EER community. Triangles represent mentees; squares represent mentors; circles represent members of the EER community (not surveyed).

Four of the mentee–mentor pairs (depicted as yellow, violet, cyan, and orange shapes), were “isolate” groups; isolate is a term that indicates that these pairs did not collaborate with other community members. The mentors corresponding to these pairs (the orange and cyan shapes) were in social science fields adjacent to EER, and they may interact more with members of their own academic communities than the EER community. Given that our data covers only the first year of the RIEF project, mentees may have been more focused on building a relationship with their mentor and focusing on RIEF project tasks than on establishing wider collaborative works in EER. The mentee represented by the green triangle did not indicate they were collaborating with their mentor, and this is why they are represented as an isolate group. We assume this is a response error. Six mentors (depicted pink, light purple, blue gray, brown, and green squares) serve as bridges between the larger network, with mentor/mentee pairs connecting only to one or zero other pairs directly.

VI. LIMITATIONS AND FUTURE WORK

Our work follows RIEF mentees during the first year of their enculturation into the EER community. This year coincided with the COVID-19 pandemic year(s) when travel and in-person events in the EER community were canceled or severely limited. It is difficult to know how the pandemic affected network development. To better understand this, we are seeking additional funding to follow this cohort of mentees for an extended period and compare their network development to later RIEF awardees who were potentially not as affected by in-person restrictions. We believe that conducting an explanatory mixed methods study could provide additional context for our current findings and also help explicate the pandemic’s effect.

VII. SUMMARY OF FINDINGS AND CONCLUSIONS

Overall, we found that RIEF mentees’ social networks for EER grow over the first year of their RIEF project, which

indicates that they are becoming enculturated into the research community. Specifically, mentees reported more professional interactions with key individuals in the EER community after one year than when initiating their projects (reported in Table II and visually depicted in Fig. 2). While two mentee–mentor pairs had no communication about their projects with individuals from EER community who were listed on the survey, the remaining mentees reported increased communication about their own research with others in the EER community over the first year of the project (Fig. 4, Table III).

We found that some mentors, while having the requisite social science expertise required by NSF solicitation, do not have ties to key individuals in the EER community, whereas some mentors are extremely well-connected. When RIEF mentors are not initially part of the EER community, their mentees' EER social networks may differ in characteristics than mentees whose mentors have a higher number of connections to community members. Specifically, mentees whose mentor was not connected to EER community members did not collaborate with other community members, whereas mentees whose mentor was connected to individuals in the larger community showed more collaboration with other RIEF mentee–mentor pairs and with individuals from the closed list of community members. These findings indicate that opportunities exist to strengthen RIEF mentees' interactions with members of the EER community and speed their enculturation through selection of well-connected mentors.

VIII. IMPLICATIONS AND CONTRIBUTION

While other studies about EER mentoring programs for faculty [11], [13], [14] have focused on qualitative aspects of the mentoring relationship, our work *quantitatively captures temporal changes* in novice researchers' social capital. Our research *operationalizes enculturation* of novice researchers into the EER community in concrete ways and underscores the importance of selecting highly connected mentors in order for a mentee to maximize professional interactions, communication, and collaboration with EER community members.

Our findings concur with and build on qualitative studies that have found that building capacity in EER relies not only on technical skills but also building social capital. Building social capital within EER not only enhances the mentees' connections in the field, but also supports their sense of belonging [13] and their ability to overcome barriers in transitioning into a new academic discipline [25]. For these reasons, we suggest that mentees in capacity building programs select mentors who are well-connected in the EER community and craft a mentoring plan that also leverages their mentor's network. We also recommend that mentees in research initiation programs like RIEF consider including an advisory board who can add technical expertise while also supporting the mentee's enculturation in the field by expanding their EER-based network beyond that of the primary mentor. Additional connections provided by advisory board members will not only benefit the mentee's network growth but will likely provide additional opportunities to support sustained engagement in the EER community (e.g., opportunities to join editorial boards,

collaborate on future projects, and assume leadership positions).

Well-connected mentors need to share their social capital in EER in order for their mentees to grow their network. The connections between RIEF mentee–mentor teams are likely to be a result of a RIEF virtual community of practice [26] that existed during this timeframe. We posit that such community structures are important to ensure the success of programs like RIEF to develop social capital and support continued participation in EER beyond the duration of the RIEF funding.

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